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CAINOZOIC AND GENERAL

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13. with G. Hall and T.D. Hughes - Structural Map of Tasmania - 1:506, 880. *Tasm. Dept. Mines.*
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14. Geology and Mineral Deposits. In Davies, J.L., (ed.): ATLAS OF TASMANIA, Dept. of Lands Tasm., 12-17. 1965.

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THE UNIVERSITY OF TASMANIA
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A COMPARISON OF JURASSIC AND TERTIARY TRENDS IN TASMANIA.

Maxwell R. Banks.

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A COMPARISON OF JURASSIC AND TERTIARY TRENDS IN TASMANIA.

Maxwell R. Banks.*

Abstract.

The directions of 231 structures associated with the Tasmanian dolerite, approximately Jurassic in age, have been measured and plotted. The distribution is not random (probability of random distribution is just less than 0.01) and maxima occur mainly at 9°, 335° and 38°. The dominant directions of Jurassic or pre-dolerite (post-Middle Triassic) faults are 308°, 37°, and 44° approximately with dykes mainly about 350°, 9°, 25° and 40° approximately. Several epochs of faulting and dyke formation are suggested.

An analysis of the directions of Tertiary (and Quaternary) faults shows that the distribution is not random (probability of random distribution is much less than 0.01). The preferred direction is 333° but other maxima occur mainly at 316° and 359°. At least three and perhaps as many as six epochs of faulting are suggested.

Introduction.

This comparison arose from a curiosity concerning the possibility of variation in stress environment in Tasmania between the time of intrusion of the dolerite and the Tertiary Period. It was hoped that the analysis of the trends associated with the dolerite might reveal a significant simple pattern and make field mapping easier in future.

The author wishes to acknowledge helpful discussions with Dr. E. Williams, Geology Department, on structural matters and with Mr. P. Sprent, Mathematics Department, on statistical matters. However the author is entirely responsible for any errors in method or interpretation.

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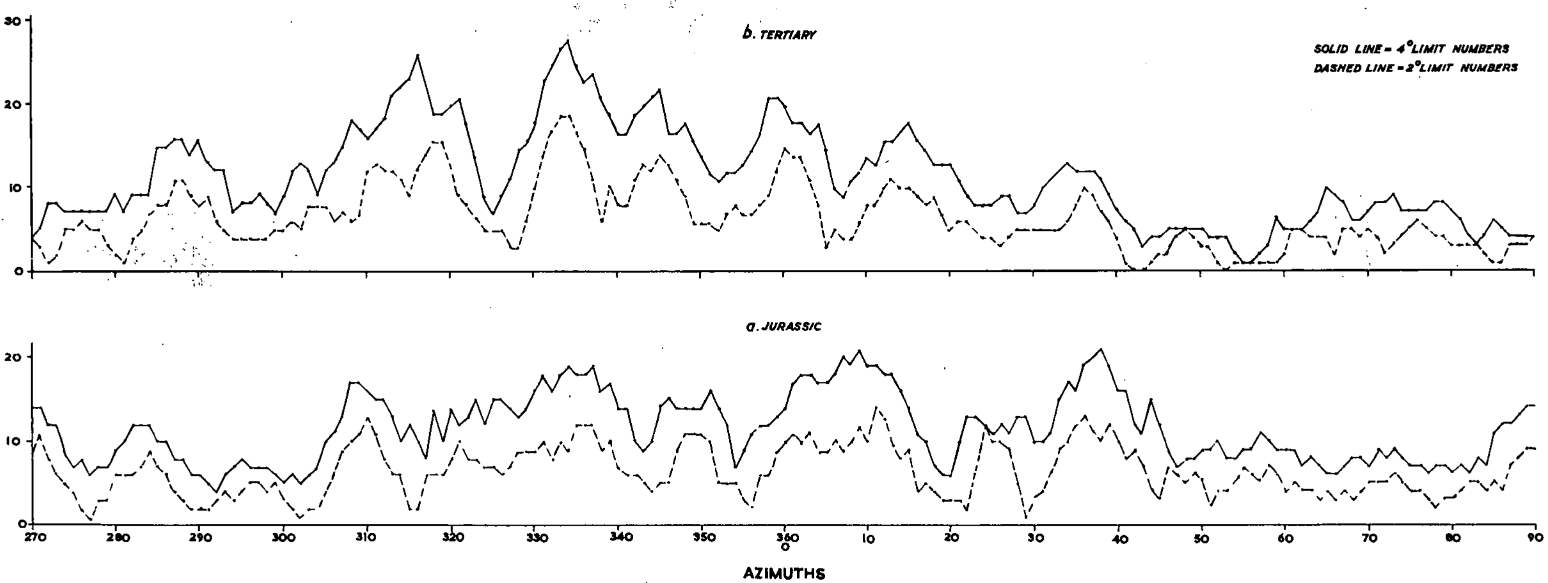


FIG. I GRAPHS OF LIMIT NUMBERS

Distribution and Form of Dolerite Bodies.

The distribution of the main masses of dolerite within Tasmania was shown in a map by Edwards (1942) and will be seen from that map to be mainly in the central, south-eastern and eastern part of the island. However, Edwards did not show all the outlying bodies. Dolerite occurs at Point Hibbs and Pyramid Island south of Macquarie Harbour. There it intrudes Permian rocks as a shallowly transgressing sheet rising stratigraphically to the south and east. Just north of Firewood Siding, about 13 miles south of Zeehan, dolerite intrudes the Permian up to the level of the Cygnet Coal Measures. Dolerite was recorded by Reid (1925) from Dundas as a dyke intruding Cambrian rocks and by the same author (1918) from the Boco Plains area north-west of Rosebery where it again forms a dyke in the Cambrian rocks. Near Waratah Nye (1923) noted several dyke-like bodies of dolerite in Cambrian rocks. Spry (this volume) notes a cone sheet on the Pieman River north of Zeehan where the dolerite intrudes Precambrian and Permian rocks. ~~A cone sheet may also be present in the lower Permian rocks.~~ A cone sheet may also be present in the lower Permian sediments near Takone, south of Burnie and a dyke-like mass of dolerite occurs in Permian sediments at Preolenna in the same area. Several dyke-like bodies of dolerite occur in the Mathinna Group rocks at Lisle (Twelvetrees, 1908) and near Ringarooma (Nye, 1924).

The dolerite occurs mainly as dykes, transgressive sheets, cone sheets and sills in the flat-lying Permian and Triassic rocks and the form in these rocks is dealt with in more detail by Carey (this volume). The author is concerned in this paper with the directions of the dykes, either intruded along faults or filling dilatational cracks, steep intrusive contacts, usually locally developed steep parts of more shallowly transgressive sheets, and of faults associated with the intrusions.

Distribution and Character of Tertiary Faults.

The position of many of the faults is shown by Banks (1958). They occur mainly associated with four major complex grabens, the Port Sorell-Tamar Graben, the Oyster Bay Graben, the Derwent Graben and the Macquarie Harbour Graben but a few occur outside these structures. As far as is known they are steep normal faults but only in rare cases has the dip of the fault plane been determined. No clear evidence of transcurrent movement is yet available. Many people in the past have postulated a fault control for the Tasmanian coastline and this is clearly shown along the east coast, in the Derwent estuary and near Macquarie Harbour. These faults control the major physiographic features in the eastern half of the island.

The Age of the Dolerite in Tasmania.

The dolerite intrudes sediments of Permian and Triassic age. The youngest dated sediments intruded are the so-called "Feldspathic Sandstones" which contain a rich flora which includes Phoenicopsis elongatus, several species of Johnstonia, Pterophyllum, Thinnfeldia, and Stenopteris. Closest affinities are with the Ipswich Coal Measures of Queensland and the Molteno Beds of South Africa. The Ipswich Coal Measures are considered by Jones and de Jersey (1947, p. 82) to be approximately Middle Triassic by correlation with the Wianamatta Group and Hawkesbury Group of New South Wales. Browne (David and Browne, 1950, p. 435) consider that Cyclotosaurus in the Wianamatta Group indicates a basal Keuper age.* The Molteno Beds are considered (du Toit, 1954, p. 357) to be pre-Rhaetic.

Palynological work is in progress in Melbourne on coals from the "Feldspathic Sandstone" which may lead to more accurate dating.

Thus the dolerite is younger than Middle Triassic. The upper limit on its age is provided by its relationship to Tertiary beds in the Launceston area. At St. Leonards a bauxitised surface developed on the dolerite is overlain by Tertiary fresh-water sediments (Carey, 1947; Owen, 1954, p. 117). These latter were deposited in a complex graben developed by faulting of the bauxitised dolerite surface. The fresh-water sediments include lignites at Rose Rivulet and Trevallyn which contain two pollens, Trisaccites micropterus and Ephedra notensis (Gill and Banks, 1956, p. 12; Cookson, 1957, p. 45) which indicate an early Tertiary age. The limits on the age of the dolerite are, then, Middle Triassic and Lower Tertiary.

In an attempt to obtain a more precise age, an analogical argument has in the past been advanced. The Tasmanian dolerites are petrologically very similar to the Karroo dolerites of South Africa. These intrude beds up to the Cave Sandstone which is considered to be Upper Triassic (Du Toit, 1954, p. 357). In places the dolerite intrusions have acted as feeders to surface flows, part of the Stormberg Volcanics, which are dated as Liassic on the basis of an Otozamites in a sedimentary intercalation in the Lebombo Lavas (Walker and Poldevaart, 1949, p. 602). A higher

* See Addendum page 251a

limit on the age of the Karroo dolerites is the presence of dolerite boulders in Lower Cretaceous beds near Port St. Johns (Du Toit, 1954, p. 370). Thus by analogy the Tasmanian dolerite is considered to be Jurassic, possibly Lower Jurassic.

The Age of "Tertiary" Faulting.

A critical area for determining the age of this faulting is in the Launceston area where Gill and Banks (1955, p. 12) adduce evidence for an early Tertiary age for some of the faulting. At Trevallyn and Sandy Bay beds deposited in graben are themselves affected by faulting so that there were at least two periods of faulting. Beds at Koyule, near Strahan, which post-date the disruption of the Henty Surface by faulting are themselves faulted. The Henty Surface is considered (Bradley, 1954) to be approximately Pliocene in age and is certainly post-Lower Miocene. Detailed evidence for this will be presented elsewhere. Thus in the Strahan area there is evidence of post-Lower Miocene faulting. Recently Banks (1957, p. 59) has suggested that faulting may be still active in the Bass Strait area. Thus it would appear that faulting has occurred in Tasmania throughout the Cainozoic. No attempt has been made on the map or in the statistical treatment to differentiate the faults in terms of age.

METHOD.

Quantities Measured.

The directions of Jurassic dykes, faults and steep intrusive contacts were measured on many maps or in some cases on the ground by the author. All directions were then recalculated and recorded as relative to true north and as bearings in the northern half of the compass circle. Directions only were measured and not lengths so that a straight fault ten miles long was recorded as a single bearing, whereas a structure only a mile long which bends and thus shows two trends was recorded as two bearings. The trends of dykes and faults were measured irrespective of their length but with steep contacts only those parts which appeared straight for more than a quarter of a mile were measured. This latter restriction resulted in only a small percentage of the total length of the steep contacts within a ten kiloyard square being considered, especially in some squares in the Huon area. No attempt was made to measure or record the amount ~~of~~ or direction of dip of the structures. No consistent attempt was made either to recalculate the strikes of Jurassic structures to compensate for the dip of the beds or effects of Tertiary faults. This was done in a few cases but because of the low dips involved the effect was normally only to displace the bearing one or two degrees. Because of all the other uncertainties of measurement and the analytical method adopted, this displacement is not critical.

Criteria for Distinction Between Jurassic and Tertiary Structures.

The age of some structures affecting Permian and Triassic rocks has been the subject of acrimonious debate. There is no real difficulty with dolerite dykes which cause metamorphism on both sides. Where these are associated with faulting, beds on one or both sides may be shattered and drag dipped but the fine grainsize of the dolerite and the metamorphism of the sediments close to the contact is used to indicate a "dolerite" age. There is more difficulty with steep contacts between dolerite and sediment. These could well be Tertiary faults unless evidence of chilled margins and metamorphism is observed. In some cases these steep contacts, even when intrusive, show drag dip and in at least two cases this is at first sight anomalous. In a contact on the Huon Road (co-ordinates 516.4, 718.6) the drag dip indicates dolerite side up and the dolerite is on the hanging wall so that the impression of a thrust is created. In an exposure south of Blackmans Bay (co-ordinates 5191. 703) first described and figured by Johnston (1886, p. 310) the dips in the Grange Mudstone on both sides of a steeply dipping sheet are down towards the sheet, this being taken as due to viscous drag of a stiff magma. Jennings (1955, pp. 186-7) mentions contortion in Triassic sediments at an intrusive dolerite contact near Wayatinah. Jennings also mentions the use of quartz veins in the ~~seid-~~sedi-ments close to a contact as indicating a "dolerite" age for the contact. Basaltic dolerite dykes have been recorded by a number of workers e. g. Prider (1948) in the Tarraleah area. Where these intrude Tertiary terrestrial sediments as in the Bronte area, no confusion with the Jurassic dolerite is possible, but if they cut Permian or Triassic sediments ~~at~~ or Jurassic dolerite, they can be differentiated from dykes of the latter only on petrological grounds, and where intrusive into Jurassic dolerite the possibility of a later Jurassic intrusion could only be negated after detailed petrological study. Dolerite dykes associated genetically with the Tertiary basalts have been noted by several workers. Where these intrude Tertiary terrestrial sediments as at the road crossing over Wentworth Creek (square 4380) (Prider, 1948) no question arises of them being associated with the Jurassic dolerite. Where they intrude

Permian or Triassic sediments or Jurassic dolerite as in several places in the area adjacent to the Nive River (squares 4380, 4480, 4379) as on Hornes Creek and Wentworth Creek (Prider, 1948) they can be established as Tertiary in age only after petrological work. The possibility of several phases of intrusion during the Jurassic has to be considered.

The ages of faults are more difficult to determine. Where the faults terminate against extensive dolerite bodies and are not represented within or along the margins of those bodies by shatter zones, the faults are presumably pre-dolerite or associated with the dolerite. Where fault zones or planes are intruded along part of their length by dolerite they are also presumably pre-dolerite or associated with the dolerite. A steep contact of dolerite against sediment lacking signs of intrusive character is presumably post-dolerite and if there is shattering of the rocks on either side of the contact surface a post-dolerite age is even more likely. Where there are contact metamorphic effects, chilling and shattering both in the sediment and the dolerite two periods of movement might be postulated, one in the Jurassic, and a renewal in the Tertiary. Faults displacing dykes or steep intrusive contacts laterally are presumably Tertiary as also are faults displacing sills and/or Permian and Triassic sediments. In the latter case a Jurassic age cannot be ruled out unless displacement of a Jurassic feature is demonstrated. Normally physiographic criteria might also be applied with freshness of the fault scarp or fault line scarp indicating a Tertiary age. However, not infrequently Jurassic faults are strongly expressed physiographically because of the resistant nature of the associated dolerite. Where a fault scarp has acted as the wall of a lowland in which Tertiary terrestrial sediments have been deposited, a Tertiary age for the fault is probable but where it involves dolerite on the upthrown side, development from a Jurassic fault is not impossible. Even where it affects only Permian and Triassic sediments it is still possible that it was initially Jurassic and has been exhumed or had later movement on it. Where the fault affects Tertiary sediments as at Trevallyn and Sandy Bay it is clearly Tertiary.

In this analysis an attempt has been made to differentiate the structures according to the criteria described above. This has resulted in the omission of some faults and steep contacts where sufficient evidence of age is not shown on the map, in the published description or in the field.

It is perhaps easier to establish that a fault is pre-dolerite or associated with the dolerite than that it is Tertiary within the background of Tasmanian conditions.

Sources of Information.

Most of the structure measured are shown on maps drawn on 20 chs. / 1" and published as part of the University of Tasmania, Geology Department 1 inch series, or prepared for publications in that series. Authors of such maps include B. F. Glenister, G. E. A. Hale, R. J. Ford, R. P. Mather, M. L. Yaxley, T. H. Rodger, A. Alwar, D. R. Woolley, I. McDougall, A. T. Wells, J. McKellar, D. H. Green and K. R. Walker. Other structures are shown on maps published by K. G. Brill, S. W. Carey, and M. R. Banks incidentally in papers from the Geology Department. Unpublished observations by the author in the Point Hibbs, Hobart and north-eastern part of the state have also been used. Many of the structures are shown on maps produced for the Hydro- Electric Commission by R. T. Prider, R. W. Fairbridge and A. H. Voisey and later published as papers in the Royal Society of Tasmania.

The maps published by the Geological Survey of Tasmania in the Coal Resources, Oil Shale Resources, Underground Water Resources and Limestone Resources Bulletins as well as some in the normal survey sequence of bulletins, also showed structures used in the analysis. Many of the structures shown in these bulletins could not be used because of uncertainty as to their age. Many dykes in the Blue Tier area were omitted because of their close association with granitic rocks, lack of detailed petrological evidence, degree of alteration and insufficient field evidence of a Jurassic age. It is distinctly possible that the several swarms there are late magmatic differentiates of the intruded granites.

All structures used in the analysis are listed in Appendices I and II where their co-ordinates or location and the name of the author are recorded. Co-ordinates are listed in terms of the state grid system as shown on the state 4 mile and 8 mile sheets. In all, structures associated with the dolerite have been measured in 61 10 kiloyard squares representing about 2,000 square miles (somewhat less than 10% of the area of Tasmania and about one third of their total outcrop area (Edwards, 1942, p. 451)). Tertiary structures were measured in 75 10 kiloyard squares, representing about 10% of the island.

Analysis.

The measurements of direction made on the Jurassic and Tertiary structures were subjected to various forms of analysis.

In the first place the measurements were placed in order from 270° through 360/0° to 90°. It was noticed that some bearings were repeated several times. Those bearings with frequencies markedly higher than normal were noted.

Because of the uncertainties of field measurement, plotting and measurement on the maps, conversion of the bearings to true north, the experimental error of the final recorded measurement is probably of the order of one or two degrees so that the high frequencies at any one azimuth may be accidental. To remove this factor of chance the number of bearings within two degrees of any azimuth was counted and these plotted in graphical form. These are referred to later as 2° limit numbers.

In order to generalise these results still further and find those directions of greatest significance the number of bearings within 4° of any azimuth (4° limit numbers) was then counted and plotted as before when some maxima showed up very strongly.

It was clear at this stage that the Jurassic trends differed in many ways from those of the Tertiary. To test whether these differences were significant and to find out whether the distribution of each group was random or not, the bearings were grouped into classes in two ways: Firstly in classes with limits such as 1° - 5°, 6° - 10°, 11° - 15° etc. and then into classes with limits 1° - 10°, 11° - 20°, 21° - 30° etc. Each grouping of classes was then subjected to a χ^2 test the null hypothesis being that the bearings were randomly distributed.

By picking the class limits in this way, it is possible that accidentally a particularly favourable or unfavourable choice had been made which would be reflected in the probabilities obtained. To test this class limits of 3° - 7°, 8° - 12° etc. 3° - 12°, 13° - 22°; 5° - 9°, 10° - 14°; 5° - 14°, 15° - 24°; 7° - 11°, 12° - 16°, 7° - 16°, 17° - 26°; 9° - 13°, 14° - 18°, 9° - 18°, 19° - 22° were also used and probabilities calculated for random distribution in each case. As a final test the maximum of the graphs of the 4° groupings ~~were~~ was made the starting point for similar classes and the same test applied. In this way it was hoped to reduce the possibility of skewing the results by accidentally placing all the bearings near the maximum in the one class.

As this test with the Jurassic showed that the χ^2 test did not give consistent results Mr. P. Sprent was approached and suggested a test for randomness based on a paper by Greenwood and Durand (1955) which dealt with circular distributions. To carry out this test all bearings were recomputed so as to lie between 0^o and 180^o, i. e. 180^o was subtracted from those lying between 270^o and 360^o. Each bearing was then doubled, i. e. 45^o became 90^o, 60^o became 120^o etc. The quantity

$$R_j = \sqrt{(\Sigma_j \cos 2\theta_j)^2 + (\Sigma_j \sin 2\theta_j)^2}$$

was then computed for the Jurassic bearings where θ is the bearing between 0^o and 180^o. A similar quantity

$$R_t = \sqrt{(\Sigma_t \cos 2\theta_t)^2 + (\Sigma_t \sin 2\theta_t)^2}$$

was calculated for the Tertiary bearings. To test for variation from a random distribution in each case the values of

$$\frac{R_j^2}{N_j} \quad \text{and} \quad \frac{R_t^2}{N_t}$$

were determined where N_j, N_t are respectively the number of Jurassic and Tertiary trends measured, and the value compared with values of Z in Table 2 of Greenwood and Durand (1955, p. 236) from which the significance of variation from randomness at the 1% and 5% levels can be established.

A study of the graphs of limit numbers suggested that the two sets of readings would have different preferred directions. To see if this was so three further values were calculated as under:

$$R = R_j + R_t$$

and

$$R = \sqrt{(\Sigma \cos 2\theta_r)^2 + (\Sigma \sin 2\theta_r)^2}$$

where $\Sigma \cos 2\theta_r = \Sigma_j \cos 2\theta_j + \Sigma_t \cos 2\theta_t$

and $\sum \sin 2\theta\, r = \sum_j \sin 2\Theta_j + \sum_t \sin 2\Theta_t$

and $N = N_t + N_j$

From these another value

$$F = \frac{(N - 2)(R' - R)}{(N - R')} \qquad \text{(Watson \& Williams, 1956)}$$

was computed and the probability of difference in preferred direction read from F tables.

The preferred direction Θ is given by

$$\cancel{\mathrm{artan}\ 2\Theta =}\ \mathrm{artan}\ 2\theta = \frac{\sum_j \sin 2\Theta_j}{\sum_j \cos 2\Theta_j}$$

and

$$\cancel{\mathrm{arsin}\ 2\Theta =}\ \mathrm{arsin}\ 2\theta = \frac{\sum_j \sin 2\Theta_j}{R_j}$$

Sprent comments (pers. comm.) " These tests are only approximate as they are based on a circular normal distribution. In our case we do not seem to have such a distribution, but rather, if the distribution is not uniform, a multimodal distribution. In such a case one might reasonably expect the above tests not to be fully efficient. If a significant departure from our hypothesis of uniform distribution (or identical preferred direction) is observed we can be confident of the validity of our results. However, in the case of non-significant results from the above tests, we might, with other more appropriate tests, detect significance."

Trends Associated with the Dolerite.

The results of the analysis of the trends associated with the dolerite are perhaps best expressed in tabular form as below -

Table 1.

Total Number Measured: 231

A (1.28)	B. (6.42)	C (11.55)	D
349°: 5(2.16%)	11°: 14(6.06%)	9°: 21 (9.09%)	9°
13°: "	310°: 13(5.63%)	38°: " "	335°
25°: "	36°: " "	334°: 19 (8.23%)	38°
312°: 4(1.73%)	335°: 12(5.2%)	337°: "	309°
319°: "	336°: "	308°: 17(7.36%)	351°
335°: "	337°: "	309°: "	270°
337°: "	24°: "	351°: 16	
359°: "	271°: 11(4.75%)	270°: 14 (6.06%)	
10°: "	349°: "	271°: "	
26°: "	2°: "	89°: "	
35°: "			
37°: "			
48°: "			
89°: "			

Column A of this table contains those bearings at which there are more than 1.5% of the total number of bearings. The figure in brackets beside the letter A, 1.28, refers to the number of bearings expected at each azimuth assuming an even, i.e. random, distribution of bearings. This is 0.55% of the total.

Column B refers to those azimuths of which the 2° limit number exceeds 11(4.75% of the total number of bearings) and includes all the maxima on the 2° limit number graph which are significantly above the number (6.42 = 2.78%) expected assuming random distribution.

Column C contains those azimuths which occur at or near the maxima on the 4° limit number graph and includes those maxima with limit numbers greater than 14 where the expected number is 11.55 (= 5% of the total number).

In column D are shown those maxima on the 4° limit numbers graph which have limit numbers of 14 or greater.

Six maxima are shown in Column D of which only three, 9°, 335°, and 38° exceed 150% of the expected limit number. In order to determine the probability of the distribution of maxima found being due to random distribution the bearings were considered in classes of 5^{o} and 10^{o} spread and subjected to a χ^2 test as used by Krumbein (1939). These show a probability that the distribution is random of 0.32 using classes of 5^{o} spread, and 0.18 using classes of 10^{o} spread. From this it would appear that the distribution could be random. To check this with special reference to Jizba's objections to Krumbein's method (Jizba, 1953), different class limits were chosen and probabilities determined by the same test. The results are tabulated below as Table 2.

Table 2.

a.

Class Limits	1 - 5	3 - 7	5 - 9	7 - 11	9 - 13
χ^2	38.29	57.5	49.35	55.28	69.65
d.f.	35	35	35	35	35
P	0.32	0.0008	0.0526	0.0136	0.0003

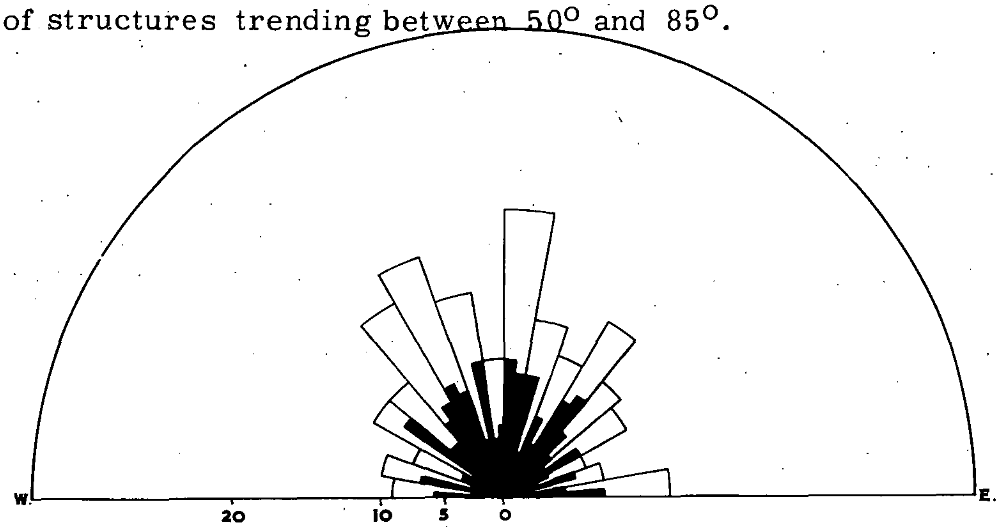
b.

Class Limits	1 - 10	3 - 12	5 - 14	7 - 16	9 - 18
χ^2	22.18	27.21	30.90	24.36	27.78
d.f.	17	17	17	17	17
P.	0.18	0.057	0.021	0.113	0.047

From this it will be seen that class limits favouring randomness were chosen first and that the probabilities of random distribution vary at least from 0.0003 to 0.32 depending on the class limits chosen. Thus in this problem at least the χ^2 test does not give an unique answer.

The test of variation from a random distribution as outlined earlier was then applied. The value of R_j^2/N_j is 5.90 which is greater than the 1 percent value of Z for an infinite number of readings (Table 2, Greenwood and Durand, 1955, p.236) so that there is less than 1 chance in 100 that the distribution is random. From this it might reasonably be inferred that the distribution is not random. The preferred direction was then calculated, assuming a circular normal distribution, and found to be approximately 357^{o}.

Because of the occurrence of three more or less equal maxima on the 4^{o} limit number graph (figure 1b) it might be inferred that the distribution is poly-modal rather than circular normal. The preferred direction calculated then indicated somewhat more readings in the north-westerly quadrant than in the north-east but the skewness is not very marked. From the graph it can be seen that there is a marked lack of structures trending between 50° and 85°.



HISTOGRAM OF JURASSIC TRENDS

CLASS LIMITS 1-5,6-10 SOLID BLACK
1-10,11-20 OUTLINE ONLY

FIGURE 2a

The polymodal character of the graph may reflect a number of preferred directions, each direction representing one epoch of tensional faulting, or a direction of least pressure during development of the dykes (see Anderson, 1942, Chap. 111). In the latter case the location of dykes may be partially controlled by pre-existing joints in the Permian and Triassic sediments. The directions of dykes and those of faults were then analysed separately. There are marked maxima in the 4° limit number graph for faults at 308° - 309°, 36° - 37° and 44° and for dykes at 348° - 351°, 9°, about 25° and at 38° - 41°. Maxima occur in the 4° limit number graph for steep contacts at 320°, 334° - 339°, and 11° to 12°. Most of the dykes near the 25° maximum occupy faults. Thus the maxima in the Jurassic 4° limit number graph seem to represent maxima in different populations in varying combinations and the more random distribution shown by the Jurassic directions as compared with the Tertiary is due to this factor and perhaps also to the occurrence of more or less circular cone sheets. It is interesting to note that in the fault distribution there are two maxima approximately at right angles but the meaning of this is unknown.

It would appear that the directions used in this analysis could well belong to several populations which are pre-dolerite or associated with the dolerite. The occurrence of four maxima in the 4° limit number graph for the dykes suggests several epochs of dyke intrusion.

This analysis has perhaps shown the need for more detailed work on the structure of the dolerites. Except for Johnston (1888) most people have envisaged the intrusion of dolerite as a single event and Johnston's ideas were based on evidence no longer acceptable. The polymodal distribution may be due to insufficient readings in any category, or to fortuitous combinations of readings of a few structural populations, but may well indicate pre-dolerite faulting and folding of the Permian and Triassic sediments. Detailed structural analysis is required before adequate generalisations can be made.

Trends of the Tertiary Faults.

The results of the analysis of the directions of the Tertiary faults are shown in tabular form below:

Table 3

Total number measured 233.

A (1.29)	B. (6.45)	C (11.65)	D
289° :6(2.58%)	33° :19(8.15%)	334° :28(12.02%)	
312° :5(2.15%)	334°:19	316° :26(11.17%)	334°
335° :5	318°:16(6.87%)	345° :22(9.45%)	316°
341° :5	319°:16	358° :21(9.02%)	345°
1° :5	360°:15	359° :21	359°
2° :5	345°:14	308° :18(7.73%)	
318° :4(1.72%)	311°:13	15° :18	
319°			
320°			
332°			
333°			
334°			
346°			
11°			

This table is arranged similarly to Table 2. From this it will be seen that the greater maxima all occur within the north-west quadrant with the maximum near 334°.

Application of the χ^2 test to this distribution showed in every case that the distribution was very unlikely to be random. The results are tabulated below as Table 4.

Table 4.

a.

Class Limits	1 - 5	3 - 7	5 - 9	7 - 11	9 - 13
	95.66	86.69	95.24	84.24	88.21
d.f.	35	35	35	35	35
P.	<0.01	<0.01	<0.01	<0.01	<0.01

b.

Class Limits	1 - 10	3 - 12	4 - 13	5 - 14	7 - 16	9 - 18
	69.16	58.68	53.24	52.7	48.32	66.62
d.f.	17	17	17	17	17	17
P.	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

The test of variation from a random distribution as outlined earlier was then applied. The value of R_t^2/N_t is 16.9 which is much greater than the 1% value of Z for an infinite number of readings (Table 2, Greenwood and Durand, 1955, p.236). From this it may be concluded that there is much less than 1 chance in 100 that the distribution is random, so that the distribution can safely be considered as showing a marked or several marked preferred directions. The preferred direction was calculated, assuming a circular normal distribution, and found to be 333°. This is remarkably close to the maximum on the 4° limit number distribution graph. From this it may be concluded that the dominant direction of Tertiary (or Quaternary) faults in Tasmania is about 333°.

As will be seen by inspection of the limit number graph (figure 1b) for the Tertiary other maxima occur but the higher ones are all in the north-westerly quadrant. Lower ones occur at about 15°, and 287° with another still smaller one at about 34°. Only that at 15° is more than 150% of the expected value. Only the 287° and 15° maxima are at all close to 90° apart, and all the others have no significant maxima at right angles to them. It is clear that the great majority of Tertiary faults fall between north-west and north.

While the limit number graph might be considered as indicating a single population with inadequate sampling producing the polymodal distribution shown, this is rather unlikely in view of the wide spread of the bearings and the presumed normal character of the faults. On Anderson's analysis of normal faulting dynamics such a wide spread would indicate several epochs of faulting. Assuming that maxima with more than the expected number of bearings close to them represent separate epochs of faulting, it might be postulated that there are at least three and perhaps a maximum of six phases of faulting, each phase being produced by tension from one direction. That there was more than one phase of faulting is also suggested by the pattern of faults determined in the field (see McKellar, 1957) and it is possible to determine the order of succession of the epochs from the field pattern (Dr. E. Williams, Pers. Comm.). More recent mapping by Alwar, Woolley and McDougall has also revealed fault patterns suggesting several epochs of faulting. In general it would appear that the north-west and north-north-westerly faults are the earlier ones.

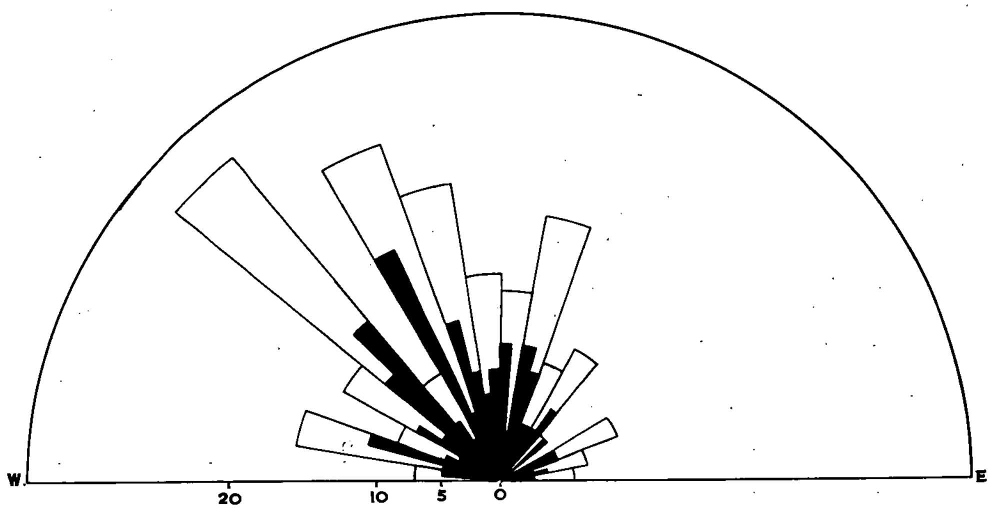
Study of the distribution of known Tertiary faults on a map (see Banks, 1958, fig. 4) shows that they form four major grabens and that the main features of Tasmanian physiography, such as the position of the highlands and the main outlines of the eastern and western coastlines, are strongly fault controlled. The Tamar - Port Sorell Graben is a complex one in which the main trends are north-west (south-east), but with a distinct tendency to swing further towards the south as traced in a southerly direction. The Oyster Bay Graben has a dominantly northerly trend but may swing towards the south-west as traced south. The Derwent Graben swings from a dominantly north-westerly trend above New Norfolk to a north-north-west trend near Hobart. South of Hobart it trends to due south and west of D'Entrecasteaux Channel swings to the south-west. On the West Coast the Macquarie Harbour Graben swings from south to south-east and again to south as traced from the Henty River to Macquarie Harbour and south of Birch's Inlet. Thus the dominant trends vary somewhat with geographical position with a rather vague convergence of the three eastern grabens towards Storm Bay.

As with the Jurassic trends, this analysis indicates the need for more critical detailed work in the field on Tertiary faults leading to detailed structural analysis.

Comparison of Jurassic and Tertiary Trends.

Comparison of the limit number graphs and rose diagrams (figures 1 and 2) for the Jurassic and Tertiary trends reveals many differences.

While both are clearly skewed towards the north-western quadrant, the Tertiary is much more markedly so. There are no high maxima in the north-eastern quadrant in the Tertiary graph while two of the three high maxima of the Jurassic graph are in that quadrant. This difference in skewness is reflected by the difference in preferred directions as calculated, 357^{o} for the Jurassic as against



HISTOGRAM OF TERTIARY FAULT DIRECTIONS

FIGURE 2 b

333° for the Tertiary. It is also noticeable that the Tertiary distribution is less random than the Jurassic. This is shown by the R^2/N values, 16.9 for the Tertiary and only 5.9 for the Jurassic.

The graphs also show that with one exception Jurassic and Tertiary maxima do not coincide. This exception is that near 334° which occurs on both graphs but is much stronger on the Tertiary. In most cases the Tertiary maxima are displaced between five and ten degrees clockwise when compared with the Jurassic suggesting that on the whole the tension directions were nearer to the east during the Tertiary than before and during the Jurassic. The maxima between 30° and 40° are not displaced clockwise but anti-clockwise.

Some analyses of joint directions in Permian rocks and the dolerite have been made. McDougall(1957) plotted 70 joint directions in dolerite near Mount Dromedary. Maxima occur at 328° and 56°. In the Eureka Cone Sheet Spry (this volume) has found joint maxima in the dolerite at 60° and 330° (308 readings). These two observations are reasonably close together and it is notable that one of these in each case is close to the highest Tertiary maximum, that in common with the Jurassic. However, it seems likely that at least this set of joints in the dolerite is due to Tertiary faulting. McDougall also plotted 45 joints in Permian rocks near Mount Dromedary and found maxima at 10° - 11°, 84° and 278°. The main set at 10° - 11° corresponds fairly well with a Jurassic maximum (9°) and may have been associated with the faulting in this direction which preceded the dolerite intrusion. The other directions may correspond to the maximum on the Jurassic trends distribution at about 270°.

In summary it may be said that tension during and before the dolerite intrusion came from different directions than during the Tertiary and Quaternary. The only maximum common to both, about 334°, is not a maximum direction of Jurassic faulting or dyke intrusion but of steep contacts. This analysis is almost certainly a premature attempt at generalisation but it has served to show the need for much more critical mapping and better structural analysis of small areas than has been made in the past in Tasmania.

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ADDENDUM

Since writing this paper the author has seen a recent paper by Watson (1958) who suggests that part of the Wianamatta Group containing Paracyclotosaurus (= Cyclotosaurus) of Browne (David and Browne, 1950, p. 435) is Upper Keuper or even Rhaetic. This amphibian comes from the Ashfield Shale (Lovering, 1954, p. 186) the basal formation of the Wianamatta Group. By correlation, therefore, the "Feldepathic Sandstone" of Tasmania is probably younger than previously thought and may be partly Rhaetic. Thus the dolerite is probably younger than Upper Triassic.

APPENDIX I.

TRENDS ASSOCIATED WITH DOLERITE

Square No.	Locality	Co-ordinates of Structure	Category	Trend	Author
4763	South Cape Bay	Little Island	d.	7	Banks
4664	La Perouse	463.9 . 646.5	d.	328	Glenister
4866	Strathblane	484.9 . 669	s. c.	61	Hale
		485.6 . 669	s. c.	312	"
4966	Dover	490 . 668.8	s. c.	87	"
5166	Sth. Bruny	Quiet Corner	d. f.	349	Reid & Keid
4867	Glendevie	488.7 . 670	s. c.	13	Ford
		485 . 671.1	s. c.	309	"
		487.6 . 680	f.	35	"
4967	Police Point	494.3 . 670	s. c.	10	Hale
		490.1 . 671	s. c.	70	"
		492.9 . 671.9	s. c.	15	"
		493.7 . 675.7	s. c.	319	"
		490.3 . 676	s. c.	316	"
		493.2 . 677	s. c.	340	"
4868	Geeveston	483.2 . 681	s. c.	323	Ford
		484 . 684.5	f.	72	"
5068	Mt. Cygnet	½ Mile from Woodbridge		359	Yaxley
		1 mile W of Woodbridge		359	Yaxley
		½ mile W of Channel Ck.		89	"
				9	"
				310	"
				329	"
				333	"
				334	"
				337	"
4769	Arve River	470 . 629.3	s. c.	89	Ford
		479.7 . 693	s. c.	335	"
		471 . 699.5	s. c.	273	"
		478 . 699.9	s. c.	89	"

4869	Franklin	482.9	.690	s. c.	307	Ford
		487.7	.693.5	s. c.	337	"
		488.3	.693.5	s. c.	35	"
		487.8	.694	s. c.	26	"
		488.3	.694	f.	312	"
		481	.694.9	s. c.	333	"
		483	.698	s. c.	349	"
		488.2	.698	s. c.	14	"
5069	Oyster Cove	503.9	.690	f.	1	Rodger
		504.2	.691	f.	335	"
		505.5	.691	f.	347	"
		504	.691.4	f	87	"
		504	.691.6	f.	41	"
		502.6	.692	f.	343	"
		503.6	.692	f.	26	"
		505	.697.8	d. f.	25	"
		503.5	.700	s. c.	319	"
		507.3	.700	s. c. in f.	307	"
5169	Snug	½ mile W. Snug		s. c. /d.	350	McDougall
		½ mile NE. Kettering			327	"
		1½ miles NNE Kettering			309	"
		2¼ Miles NNE Kettering			352	"
		2¼ miles NNE Kettering			330	"
4770	Upper Huon	470.3	.700	d.	348	Ford
		472.7	.702	s. c.	4	"
		473	.705	s. c.	13	"
		474.2	.707	d. f.	25	"
		475	.707.9	s. c.	54	"
		477	.709.3	s. c.	56	"
		470.3	.710	f.	348	"
		475	.710	d. f.	312	"
4870	Glen Huon	483.6	.701.7	s. c.	284	Mather
		486.5	.708.5	s. c.	286	"
		488.5	.708.5	s. c.	57	"
		490	.709.3	s. c.	353	"
4970	Huonville	493.8	.700	s. c.	32	"
		494	.701.2	d. f.	292	"
		490	.709	s. c.	359	"
		499	.709.4	d. f.	322	"

4970	Huonville	498.5 .709.5	d. f.	333	Mather
		494.8 .710	s. c.	1	"
5070	Sandfly	503.5 .700	s. c.	295	Rodger
		504.5 .700 - 503.8 .710	d. f.	355	"
		507.9 .700	d. f.	311	"
		506.6 .701)	d. f.	(4	"
		)		(41	"
		.706)		(22	"
		501 .702.5	s. c.	83	"
		507 .709	d. f.	26	"
		508.6 .704	s. c. d.	13	McDougall
5170	Kingston	518.5 .703.5	d. f.	(332 (	Rodger & Walker
			d. f.	(343	"
		518.4 .704	f.	(48	"
		W. of Summerleas Ag. Stn.	sc/d.	25	McDougall
		1 ml. N. Margate	sc/d	25	"
		1½ mls. SW. Margate	sc/d	37	"
			sc/d	10	"
5370	South Arm	Cape Deslacs	s. c.	89	Nye
		Mt. Mather	s. c.	342	"
5470	Slopen Main		d.	19	Brill
5570	Saltwater River		d.	338	"
5171	Hobart	Prison Farm Fault	f.	355	Banks
		Chimney Pot Fault	f.	65	"
			f.	25	"
			f.	25	"
		Upper Sandy Bay Rivulet	d. in f.	48	"
		Upper Strickland Ave.	f.	326	"
		Watchorn Hill	s. c. in f.	280	"
		Upper Proctors Rd. Fault	f.	47	"
5571	Lime Bay		d.	54	Brill
5172	Glenorchy	Montrose Rd.	s. c. in f.	7	Banks
		Humphrey Rivulet	s. c. in f.	51	"
		Gov't House Fault	f.	329	"
		Forest Rd.	f.	17	"
		N. of Islet Rivulet	s. c. in f.	81	"

5172	Glenorchy	Waverley Ave.		d.	37	Banks
		The Hollow		s. c. in f.	48	"
		Government House Fault (2)		f.	335	"
4973	New Norfolk	491.1	.730	s. c. in f.	33	Woolley
		500	.730.4	s. c. in f.	305.	"
		491	.730.7	s. c. in f.	273	"
		490	.730.8	s. c. in f.	36	"
		490.9	.731	s. c. in f.	34	"
		495.6	.731	s. c. in f.	309	"
		490.2	.731.5	s. c. in f.	1	"
5173	Claremont	E. side of Mt. Direction		s. c.	42	Nye
		Lagoon Bay		d.	60	"
5273	Richmond			d.	337	"
4774	Glenora	477.9	.740	s. c. in f.	35	Alwar
		478	.740.3	s. c. in f.	71	"
		470.9	.744	s. c. in f.	2	"
		476	.746.3	f.	272	"
4874	Macquarie Plains	487.5	.747.5	s. c.	38	"
		485	.749.3	s. c.	270	"
4974	Black Hills	499	.740.9	s. c.	338	Woolley
		500	.749	s. c.	3	"
5074	Dromedary	508.6	.743	s. c.	11	McDougall
		503.5	.743.2	d.	67	"
		503	.744.5	s. c.	310	"
		500	.745	s. c. in f.	53	"
		500.6	.745	s. c. in f.	63	"
		502	.747.3	s. c.	287	"
		501.2	.748	d.	6	"
		501.4	.748	s. c.	8	"
		500.5	.748.5	s. c.	319	"
		501.4	.748.8	s. c.	283	"
		500.4	.749	s. c.	306	"
		501	.749	s. c.	13	"
		501.2	.749	s. c.	19	"
		500.3	.749.2	s. c.	42	"
		505.5	.749.6	s. c.	5	"
		501	.749.8	s. c.	24	"
		500	.749.9	s. c.	321	"
5174	Pontville	520	.742.2	s. c.	316	"
		510	.746.25	s. c. f.	74	"

5174	Pontville	512	.746.25	s.c.f.	38	McDougall
		515.5	.747	s.c.	4	"
		516	.747	s.c.	319	"
		510	.748	s.c.	282	"
		518	.750	s.c.	299	"
4875	Mt. Spode	487.4	.750	s.c. in f.	329	Alwar
		483	.754.2	f.	297	"
		Bloomfield Fault		f.	45	"
				f.	270	"
		483.5	.754.9	f.	285	"
		483.7	.759	s.c.	323	"
4576	Repulse	459.7	.766.5	d.	37	Jennings
		459.6	.766.8	d.	352	"
		456.5	.768	s.c.	338	"
		455	.768.8	s.c.	80	"
4676	Ouse	Dee River Area		d.	77	Keid
4477	Long Spur	440	.771	f.	286	Jennings
		444.7	.778	s.c.	339	"
		448.3	.779	s.c.	0	"
		445	.779.6	s.c.	57	"
		446	.779.6	f.	312	"
4577	Black Bobs	457	.770.9	s.c.	349	"
		454	.773.7	s.c.	37	"
		454	.774.5	s.c.	297	"
		457.8	.779.8	f.	16	"
5278	Parattah	Railway Line		d.	84	Nye
4379	Tarraleah	437.3	.793.4	s.c.	282	Prider
		440	.794.3	s.c.d.	56	"
		439.8	.794.5	s.c.d.	65	"
		441	.791.8	s.c.	59	"
4579	Dee River	450.5	.798.6	s.c.	301	"
5279	York Plains			d.f.	322	Nye
				d.f.	308	"
4480	Bronte	440.7	.805.6	s.c.	291	Prider
4481	Missing Link	Forest Dale Fault		d.f.	341	"
				f.	349	"
		445.5	.814.8	d.	284	"
		445.5	.814.9	d.	274	"
		445.8	.816	d.	72	"
		445.2	.816.3	d.	82	"
		447.7	.817	d.	330	"
5381		Grimes Lagoon		d.	13	Nye
				d.	O	"

5381		Grimes Lagoon	d.	41	Nye
		Mona Vale Salt Pan	d.	280	"
			d.	10	"
		E. of Mt. Anstey	d.	347	"
5382	Ross		d.	298	"
3484	Dundas		d.	344	Reid
3784		W. of Lewis Hill	d.	9	"
6084	Denison R		s. c.	350	Keid
	Apsley R.		s. c.	337	"
3285	Pieman R.	SW. side Eureka Cone Sheet	s. c.	331	Spry
5585		Mt. Christie	d.	34	Reid
3586		Boco Plain	d. f.	44	"
			d. f.	32	"
4687	Golden Valley	464.1 .872	d.	324	Wells
		467.6 .872	s. c.	359	"
		467 .872.3	s. c.	271	"
		465.3 .873	s. c.	10	"
		466 .873.4	s. c.	335	"
5887		S. of Mt. Durham	d.	11	Keid
		Spion Kop	d.	272	"
			d.	308	"
			d.	349	"
			d.	75	"
5987		Mick's Creek	d.	321	"
			d.	5	"
			d.	85	"
			d.	26	"
6088	Falmouth	601.1 .880.8	f.	311	Walker
		601 .881.5	f.	69	"
		600.6 .882.8	f.	294	"
		600.9 .882.8	f.	282	"
		600.2 .883.3	f.	11	"
		600.5 .883.3	f.	35	"
4391	Latrobe	Tasmanite Mine	d. f.	40	Reid
		W. proj. Brown Mt.	d.	278	"
		E. " " "	d. f.	48	"
		" " " "	d. f.	60	"
4792	Beaconsfield	480 .926	s. c.	324	Green
		476 .929	d.	40	"
5292	Lisle	Head of Wattle Ck.	d.	75	Reid
4792	Beaconsfield			40	Green

3593	Preolenna	Diabase Range	d.	30	Hills.

In the above list under "Category" -

"d"	signifies	a dyke,
"d. f."	"	a dyke in a fault.
"f"	"	a fault.
"s. c."	"	a steep contact.
"s. c. d."	"	steep contact of a wide dyke.

APPENDIX II

TRENDS OF TERTIARY FAULTS.

Square No	Locality	Co-ordinates of Structure	Trend	Author
4765	Ida Bay	Ida Bay Tram Line	1	Banks
		Sugar Loaf Flt.	341	Everard.
		Caves Hill Flt.	349	"
5066	Woody Island	Fault	345	Banks, Hale & Yaxley
4868	Glendevie	487.6 .680	35	Ford
4968	Police Point	Brooks Bay	17	Hale
5169	Snug	E. of O'Briens Hill	2	McDougall
		E. of Kettering	28	"
		2 mls. NE of Kettering	333	"
			320	"
		2 mls. NNE of Kettering	24	"
		Conningham Rd.	347	"
		Faults	16	"
5170	Kingston	W. of Howden	11	
		Margate	23	McDougall
		Snug Flt.	14	"
			23	"
			34	"
5171	Hobart	Neika Flt.	77	Banks
			83	"
		Cascade Fault	325, 355	Banks and Carey
		Flt. McRobies Gully	8	"
		Waterworks Flt.	50	"
		Upper Waterworks Flt.	332	"
		Turnip Fields Flt.	342	"
		Pillinger Flt.	357	"
		Ft. Nelson Flt.	12	"
		Taroona Flt.	11	"
		Salv. Army Hut Flt.	284	"
		Lansdowne Ave. Flt.	49	"
		Waimea Ave. Flt.	89	"

5471	Slopen Is.	Turner Pt. Flt.	272	Brill & Hale
		Slopen Is.	358	" "
			69	" "
5072	Berriedale	3rd Bend Fault	346	Cordwell
		Glenlusk Rd.	29	"
5172	Glenorchy	Glen. Res. Fault	291	Banks & Carey
		Hickman Fault	320	" "
		Brushy Creek Faults	312, 312	" "
		Knocklofty Fault	332	" "
		Pottery Rd. Faults	284	" "
			341	"
			336	" "
		Zinc Works	6, 352	" "
5272	Lindisfarne	Bellerive Flt.	314	Carey & Henderson
		Lindisfarne Flt.	334	"
			324	"
		Flagstaff Flt.	303	"
		Howrah Flt.	336	"
		Risdon Flt.	2	"
4573	Maydena	Pillingers Ck. Flt.	298	Hughes & Everard
		Maydena Flt.	67	" "
		Fitzgerald Flt.	304	" "
			284	" "
			278	" "
4873	Plenty	487.1 .730	2	Alwar
		487 .730.9	63	Alwar
		488.5 .731	4	"
		488.7 .731	355	"
		486.8 .731.7	75	"
		487 .732	8	"
		490 .732.7	305	"
		485.7 .735	309	"
		487 .735.1	314	"
		487 .735.9	309	"
		484.9 .739	330	"
4973	New Norfolk	498 .730	76	Woolley
		492.3 .731.8	88	"
		497.1 .732	294	"
		491 .733	318	"
		499.1 .735	$11\frac{1}{2}$	"
		490 .735.1	287	"
			89	"

4973	New Norfolk	499 .735.3	39	Woolley
		Glen Fern Flt.	318	"
		Magra Flt.	317	"
			6	"
			332	"
		Boyer Flt.	353	"
		Black Hills Flt.	338	"
			1	"
5173	Claremont	N. of Grass Free Hill	337½	Nye
		NW of Dulcot	275	"
		W. of Basin Hills	10½	"
5273	Richmond	Butchers Hill Flt.	333½	"
4674	National Park	Arcadian Siding	30	Banks
4774	Glenora	470.9 .750	306	Alwar
		Moogara Flt.	310	"
		Meadowbank Flt.	341	"
4874	Macquarie Plains	484 .749.4	311½	Alwar
		Magra Flt.	303	"
		" "	337	"
		Shatter zone	315	"
			294	"
			49	"
			346	"
			317	"
			36	"
4974	Black Hills	491.3 .740	319	Woolley
		493 .740	321	"
		490 .742.6	17	"
		490 .743.2	289	"
		497.2 .749	305	"
		497 .750	19	"
5074	Dromedary	501.5 .740	305	McDougall
		505.2 .740	334	"
		507.8 .740	356	"
		509.1 .740	1	"
		501 .740.2	78	"
		505 .740.5	30	"
		502.9 .741	289	"
		508 .741.1	276	"
		506 .741.2	309	"
		505 .742.05	347	"
		507 .741.1	324	"

5074	Dromedary	503	.743.6	316	McDougall
		501	.744.9	299	"
		500	.745.2	286	"
5174	Pontville	518.4	.740	285	"
		514	.741.9	312	"
		518.5	.742.2	276	"
		510	.749.4	319	"
5874	South Maria	Main Flt.		15	Banks
3375	Point Hibbs	North Hibbs		359	"
		South Hibbs		345	"
5675	Orford	Black Ck. Flt.		$345\frac{1}{2}$	Reid & Keid
5875	North Maria	Main Fault		20	Banks
4376	Gordon Range	436	.760.8	47	Jennings
		436	.763	315	"
		437	.784.1	61	"
		436	.766.8	281	"
		433.4	.767	335	"
		436	.767.8	63	"
		436	.768.1	63	"
4476	Misery Range	445	.761.3	46	"
		444	.761.9	276	"
4576	Repulse	459.1	.765	333	"
		454	.766.8	333	"
		456	.766.8	313	"
		457.2	.769.7	69	"
5276	Colebrook	N. Colebrook		$347\frac{1}{2}$	Nye
		S. Colebrook		$324\frac{1}{2}$	"
		Burns Creek		$343\frac{1}{2}$	"
4477	Long Spur	446	.775	318	Jennings
				310	"
				286	"
		445.5	.777	38	"
5277	L. Tiberias	E. Rhyndaston		38	Nye
4478	Nive River	Nive Bridge Flt.		72	Prider
6078	Schouten Is.	Middle ~~Park~~ Part		14	Keid
		South Part		346	"
4279	King William	428.4	.800	356	Prider
4379	Tarraleah	Nive Flt.		343	"
5079	Launceston	Glen Dhu Fault		320	Carey
		Trevallyn Fault		320	"
		Corra Lynn Flt.		318	"
		Glen Dhu Flt. (E. Branch)		332	"

5079	Launceston	Glen Dhu Flt. (SE. Branch)	289	Carey
5279	York Plains	Coal Mine Hill Flt.	341	Nye
		Nala Flt.	38	"
6079	Freycinet Penin.	Middle Part	331	Keid
		North Part	360	"
3580	Mt. Strahan	354.4 .810	2	Bradley
3381	Ocean Beach		331	Carey *et. al*.
4481	Bronte	Missing Link Flt.	0	Prider.
6081	Coles Bay	Cornwall Flt. Mt. Peter.	1	Keid
		Cornwall Flt. Coles Bay	13	"
3382	Henty River		1	Carey
3582	Yolande River	352.3 .830	347	Bradley
3383	Malanna		299	Carey
6083	Llandaff	Llandaff E. Flt.	37	Keid
4984	O'Connor Peak	495 .843.4	289	Voisey
			289	"
		496.1 .850	294	"
4785	Weston	478.3 .850	56	McKellar
		476.2 .851	16	"
		470.5 .854	68	"
		470 .856.2	62	"
4885	Palmer	484 .850	34	McKellar
		482 .854.5	344	"
		482 .856.1	344	"
		490 .859.5	277	"
6085	Seymour	Douglas R. Fault	18	Keid
		Fosters Flt. (Denison R.)	11	"
4686	Jackey	465.7 .861	33	McKellar
4786	Drys Bluff	470.9 .863	337	"
		470.7 .866	16	"
		480 .869.1	29	"
		470 .869.8	293	"
		477.4 .870	299	"
4886	McRae	482.6 .870	334	"
5586	Gipps Creeks	Ben Lomond Flt.	335	Reid
5686	Aberfoyle	Burns Marsh Flt.	37	Connolly
		Aberfoyle Fault	13	"
			35	"
		Aberfoyle No. 3 Fault.	25	"

6086	Piccaninny Pt.	Dalmayne Flt.	352	Keid
		Wardlaw Flt.	286	"
4687	Golden Valley	460.3 .873	311	Wells
		460 .875.5	311	"
5887	Fingal	Silkstone Flt.	352	Keid
5987	St. Marys.	Cornwall Flt. S. Sister	341	"
		Goulds Flt.	21	"
		Cornwall Flt. S. of St. Marys	324	"
			335	"
4688	Deloraine	469.2 .880	20	Wells
6088	Falmouth	601 .880.6	312	Walker
5389	Musselboro	Musselboro Ck.	335	Banks
5290	Mt. Barrow	N. Mt. Barrow	317	"
5390	Camden Brook	E. Mt. Barrow	543	"
4291	Paloona	Denny Gorge Flt.	2	Burns
		429 .914.5	289	"
4391	Mersey Bend		69	Reid
4491	Long Hill		333	"
5091	Karoola	Karoola	77	Banks
4492	Melrose	Eugenana Flt.	357	Henderson & Burns
4592	Franklin Rivulet		360	Reid
	Rubicon River		290	Reid & Banks
4792	Beaconsfield	473.1 .920	319	Green
		471 .927.9	329	"
		471 .927.2	82	"
		471 .926.9	319	"
		471 .926.7	81	"
		479 .926.6	301	"
		477.8 .928	330	"
		475.6 .929.4	304	"
		476.5 .928.8	74	"
			351	"
5092	Bangor	W. of Lilydale	335	Banks
5192	Lebrina	Railway N. of Lilydale	330	"

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Tertiary Fossil Forest at Macquarie Plains

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ABSTRACT

T Macquarie Plains, Tasmania, cliff and road exposures in a youthful landscape show that at least nine eruptions of basalt or saltic tuff occurred in the area late in the Tertiary. Fossil wood found on two horizons, the higher occurrence being that of opalized ees (*Cupressinoxylon hookeri* and others) in a coarse tuff in position growth, forming part of a fossil forest.

INTRODUCTION

Quarrying operations on the Dobson Highway, half a mile east Macquarie Plains Railway Station, recently revealed a number of alized trees in breccia and tuff. Opalized trees were first discovered the Macquarie Plains area by Mr. R. Barker, of the original " Rose arland " property, before 1842, and were reported on by Joseph Hooker 842), surgeon on H.M.S. " Erebus ". Several years later Strzelecki 845) recorded more observations, including those of moulds of trees basalt and of at least two basalt flows. Moore (1853) also noted em but added no fresh observations. Strangely enough, Johnston akes no comment on them in his " Systematic Account of the Geology of asmania " (1888) except to record Hooker's and Moore's papers. The ees seem to have been rediscovered several times since, judging from cal comment.

The " Barker Tree " was sent to the Great Exhibition at the Crystal alace in 1851, after which it was donated to the British Museum of atural History. This specimen was described by Arber, in 1904, ho noted that it was nine feet long by three feet wide.

The latest rediscovery was brought to the attention of the auth by a report received from Sir Rupert Shoobridge of a piece shown him by Mr. L. G. Marshall, of Macquarie Plains. Since then mai people have collected from the cutting, including Mr. F. A. Peterso who collected a piece of wood 15 in. long, and about 7 in. in diamete which he donated to the Tasmanian Museum in 1954.

The author wishes to acknowledge with many thanks the assistan of Miss E. M. Smith, of the Geology Department, who looked up tl old literature, and of Mr. A. H. Spry, of the same department, f assistance in the field.

PHYSIOGRAPHIC NOTES

This area is of considerable physiographic interest, as some of tl post-basaltic history of the River Derwent can be read here. The high hills to the north-east and the south-west with gentle to steep slop cut in Permian and Triassic rocks or dolerite contrast with the low areas of steep cliffs of basalt, giving way sharply to the flat plains the Tertiary lake sediments or river alluvium near the rivers.

The main drainage in the area is the Derwent River, wi the Styx River joining it just below Macquarie Plains railway statio The valley of the Derwent is narrow and steeply-cliffed with on occasional flat areas of deposition at or just above present river leve There are numerous insequent tributaries in the Tertiary basalts ar lake sediments. Thus the Derwent River here is high in a local valle tract. Fine slipoff and undercut slopes are shown by the Derwen especially beside the Lyell Highway near Gretna. A preliminar stage in the development of an undercut slope is frequently tl formation of landslides where basalt with well-developed vertical join ing overlies soft Tertiary sands and clays. These landslides may l seen very well in the cliff facing the Dobson Highway half a mi north of Macquarie Plains Railway Station and in Lands Dept. pho Ellendale, Run 8, No. 24154. Rapids are present near the Lye Highway and at other places along the Derwent so that the river ha locally not reached maturity. Although the general course and valle of the Derwent here strongly suggest incised meanders, the straightnes of parts of the river, as at Macquarie Plains where it flows straigl south-westerly for a mile, is an anomaly.

The valley of the Styx River around Bushy Park and Macquar Plains is wide and flat and is a local plains tract mainly developed c Tertiary lake sediments. The course of the river is very meandrin and at least one ox-bow lake has been formed. Some deposition appeai to be taking place on the inner curves of the meanders now and tl stream is usually aggrading in this area. Two terraces can be seen i the valley around Bushy Park, one 6-10 ft. above stream level and tl her about 20 ft. above the first. The slope from the higher one the lower is still very sharp, suggesting that the last is of no great ntiquity. The top terrace is not much dissected either, and it is there- re probably not very old.

The hills of basalt are frequently terraced due to the superior esistance to erosion of the lava flows as compared to the tuffs or ke sediments. The original surface of the lava plain is probably xposed on top of the hills as suggested by the accordance of the levels f the tops of the hills for some miles up and down the stream. Because art of the original surface still remains, the topography is considered be still youthful.

The history of the Derwent and its tributaries in this area has been riefly treated by Edwards (1939, p. 193) and the following is a con- iderable amplification with some differences. After the eruption of ne last lava flow we may envisage the area as consisting of wide asalt plains between steep hills of older rocks. The Styx entered this lain from the hills several miles south-west of Glenora railway station nd flowed along the south-eastern margin of the plain for about four iles before turning sharply to the south-east, where it continued to ow along the junction between the basalt and the older rocks to join he Derwent near Macquarie Plains. Due probably to pre-basaltic rosion, the Tertiary lake sediments were higher on the south-western ide of the old Derwent Valley, so that the basaltic cover was thinner nd the Styx River cut through the basaltic plain to the lake sediments nore quickly than the Derwent itself and was thus able to develop local plains tract. The Derwent immediately after the eruption of he last basalt flow meandered along the north-eastern side of the lain till it reached the resistant dolerite spur near "Rose Garland" here it swung sharply to the south-west and flowed right across the lain until it impinged on the south-western margin where it swung ack across the plain. The Derwent has since cut down into the plain ncising the meanders. A time of still-stand in base level was respon- ible for the development of the 30 ft. terrace. A later reduction n base-level was responsible for the 6 ft. terrace.

In the future, due to the enlargement of the meanders, the Derwent s likely to cut through the narrow divide just north of Bushy Park o join the Styx, leaving several miles of the Derwent course as a rge ox-bow lagoon.

STRATIGRAPHY

The succession of the rocks in the immediate vicinity of the fossil orest is summarised as fig. 1 and the position of the sections is shown n the map, fig. 2, which also shows a general sketch map of the geology nd physiography of the surrounding areas.

TERTIARY LAKE SEDIMENTS.—The only previous author ı remark on the lake sediments has been Johnston (1888), who describe briefly fossiliferous lignites and clays from near the junction of tl Styx and Derwent Rivers. In the same publication he mentioned clay with leaf and fruit impressions from a road cutting near Glenora an figured some of the leaves. The probable locality of this find is indicate on the map.

Lake sediments are also exposed in the banks of the Derwent i a number of places. The most northerly occurrence examined showed coarse conglomerate near river level and this is overlain by a fel spathic sandstone. The conglomerate is about 6 ft. thick and is poorl sorted with rounded to sub-rounded boulders of dolerite, quartz an quartzite. Basalt was looked for but not found. Although some boulder had a high sphericity, many of them were discoidal or flattish in shap and there were signs of imbrication, indicating currents from the wes or a west facing shingle beach. The latter hypothesis is preferred bı no positive evidence on the subject can be given. The conglomerate i overlain by a friable brownish-yellow to dark-brown feldspathic sanc stone. The sandstone is medium-grained with good sorting and sub angular to sub-rounded grains. It contains quartz, weathered feldspa and white mica in a clayey matrix, and is veined with earthy calcite Thick laminae and very thin beds are present and some cross-bedding again suggesting currents from the west, is present.

In a section a quarter of a mile to the south of this one, whit to yellow or brown clayey sandstone is shown. It is much thicke than at the first locality and there is no conglomerate exposed. Thi may be due to alluvium cover near the present river.

PLIOCENE VOLCANIC ROCKS.—Overlying the sandstone in th first section is a thick flow of basalt. At the base it is very vesicula with some aragonite in the vesicles. The vesicular zone passes u gradually into a zone showing good columnar jointing. This zone i about 4 ft. thick and is followed by about 48 ft. of hackly jointe basalt. The top eight to ten feet of the flow are vesicular and th top 6 in. tends to be glassy and scoriaceous. This sequence of zone within the flow is very similar to that seen in the new excavations a the eastern end of the Plenty Bridge, but was not repeated in any o the higher flows. The top 3 ft. is weathered more than the rest o the flow.

A thin layer of claystone follows. This is yellowish to brown a the base and dark grey near the top. It contains wood fibres an stem impressions. The overlaying basalt is very vesicular for abou a foot, and near the base there are signs of ropy and pillow lava. A or near the base of the flow are numerous cavities up to 20 in. acros and over 4 ft. deep which have, in places, been filled by concentricall ıminated ironstone concretions. The basalt appears to have ridden p over some objects, formerly occupying the cavities, and it is noticeably ner-grained at contact with these, as well as having radially arranged esicles up to 4 in. long over them. Some of the cavities branch and thers have impressions on the walls suggestive of wood. It is suggested nat these were originally trees knocked over and then overridden by ne basalt and carbonised by the heat of the flow. The carbon was ater removed by oxidation and some of the cavities filled with concretions f iron hydroxides.

This flow is succeeded by tachylytic tuffs and breccias. The top f the flow is very vesicular and somewhat more weathered than the est of the flow. Where the top surface is well exposed, as in the oad cutting, it is seen to be covered in a number of places by a hin veneer up to a few inches thick of sand and clay. The top of the ıva apparently had a relief of a few feet as shown by the exposures ı the road cuttings. The sand and clay member had leaf impressions nd in many places the top inch or two has been heavily stained with on.

The succeeding tachylytic breccia and tuff formation contains the palized trees. It consists largely of irregular, angular, poorly sorted agments of tachylytic and vesicular basalt, but contains also fragents of Triassic sandstone and Jurassic dolerite. The tuff shows oss bedding which dips in a southerly direction. Because of the lack f rounding and any other sign of water action, this cross bedding is onsidered to be of aeolian origin. The opalized trees apparently grew ı the underlying sandy clay, as they can be traced to within a foot of ıis band, but then begin to show signs of disintegration, which can e traced down into clay and produced cavities in the clay. The creasing degree of disintegration shown near the band of sandy clay ay be due to the freer movement of groundwater along that band. he opalization of the trees took place after they had been covered y tuff. The silica may have been derived by leaching of the basaltic uff by slow moving groundwater. At least twelve trees have been oserved to date in a vertical position. They vary from one inch up 15 in. in diameter. In one case a branch was found in position on ıe trunk. The tallest portion of a tree yet found is about 20 ft. high, ıt considering the diameter and the angle of convergence of the sides ome of the trees must have been over 60 ft. in height.

The tree presented by Mr. Peterson to the Museum showed over 30 growth rings. Considering the very much larger diameter of some the other pieces which have been found, the forest could well have een growing for over a thousand years before it was overwhelmed by ıe volcanic ash. On an A.N.Z.A.A.S. excursion in 1949, Mr. F. S. olliver, of the University of Queensland, found several fragments of bone in the breccia in the road cutting but no more have yet be found. There are at least three species of wood in the breccia, includi one described by Arber in 1904 as *Cupressinoxylon hookeri*.

In the section (fig. 1) along the south-eastern bank of the riv dolerite *in situ* was found at one place, and in another more th 30 ft. of Tertiary sandstone was followed by only 15 ft. of basa and then the lower leaf-bearing sandstone. This would indicate so relief of the pre-basaltic surface.

Over 200 ft. of continuous section are exposed in the cliffs on t north-western side of the river, but the base is not exposed as it covered by river alluvium. The lowest unit is a massive basalt whi becomes more vesicular in the top 3 ft. The top surface is irregul but there is no sign of weathering. The second unit is another flo of basalt with the basal half inch tachylytic followed by a zone 1 thick of basalt with long cylindrical vesicles. The top 3 ft. is ve vesicular and the surface is very irregular. Some weathering may present at the top surface and there is an accumulation of limoni in the joints near the contact.

A pillow lava forms the third flow. Pillow lavas have been record in the Tertiary of Tasmania only once before, at Liawenee Canal Voisey (1949). The pillows here are up to 6 ft. in length, oval a with radial cylindrical vesicles and concentric lines of spherical vesicle The pillows fit into one another and have tachylytic margins. The t few feet of this flow are very vesicular.

Another massive basalt follows with a ropy, tachylytic lower surfa and long cylindrical vesicles near the base. The top is very vesicula A thicker, more massive, but more vesicular flow follows and is succeed by a thin bed of sandy clay.

This bed of sandy clay is variable in thickness from about o inch to 2 ft. and consists of clay with some sand. The colour vari from white to red and in many places there is some evidence of sma concentrically banded concretions of aluminous and ferruginous ma erial. The top is commonly very iron-rich and this association sugges incipient lateritisation. Leaf and stem impressions are common.

A thick tachylytic tuff overlies the plant bearing sandy clay. T tuff is roughly bedded and sorted and contains lenses of breccia wi fragments up to a foot in length. While these fragments are pr dominantly of tachylytic and vesicular basalt, fragments of doleri and quartz sandstone were also seen. The fragments in the tuff a breccia are very angular and there is no evidence of deposition by wate Cross bedding was seen in this unit and was mainly directed from t north. Near the base of the tuff a number of long, cylindrical caviti up to 18 in. or 2 ft. in diameter and horizontal in disposition are prese

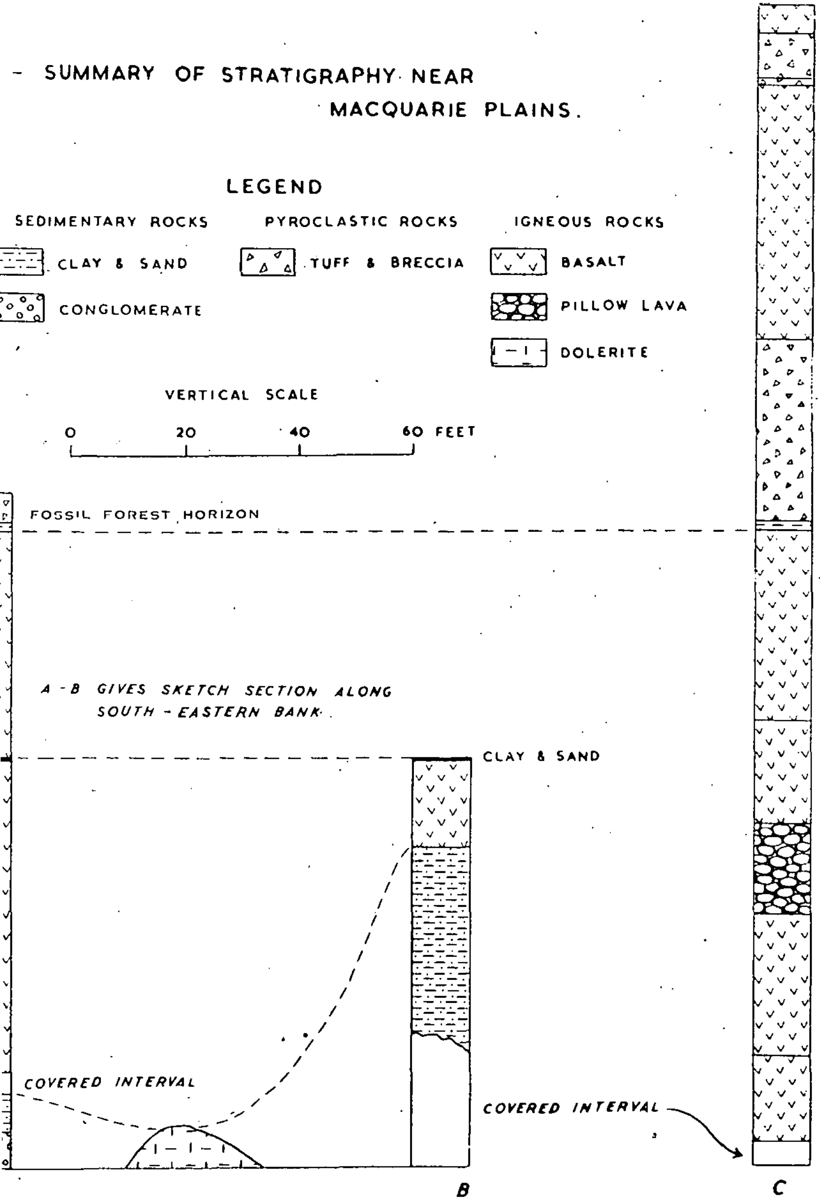

FIG. 1.—Summary of Stratigraphy of Derwent Valley near Macquarie Plains.

Some of these branch, and it is suggested that they are the cavities l by the solution of fossilised trees. Their axes lie mainly in a nor westerly direction.

The tuff is followed by a flow of massive basalt which is vesicul near the top. Another tuff overlies the basalt. The basal foot of tl tuff is medium-grained, thinly bedded and cross-bedded while the r of the unit is coarse and thickly bedded. The section is completed a flow of massive basalt.

GEOLOGICAL HISTORY

The history of the Macquarie Plains area began in the Trias Period (about 190 million years ago) when sand and volcanic ash we deposited together in swamps and lakes in which peat was also accum lating. These rocks of the New Town Coal Measures are now expos at Gretna and Plenty. A few million years later they were intruded large masses of dolerite, such as are exposed in the road metal quar a quarter of a mile north-west of the Rosegarland Hotel, and in the b of the Derwent half a mile upstream from Macquarie Plains Static A long period of erosion followed, of which there is no direct eviden in the area, and then early in the Tertiary Period (more than fif million years ago) faulting caused the development of large valley running north-westerly with a gentle slope from the north-east, as shown by the exposures in the road cutting at Plenty, and a ste south-western scarp. In these fault valleys lakes quickly develope Lake Glenora probably stretched from slightly north of Glenora, sout easterly at least as far as a dolerite promontory at Macquarie Plair and perhaps around the south-western end of this to Plenty. The weste shoreline probably lay a few miles south-west of Glenora and ra north-east almost to Bushy Park where it turned and ran sout easterly again. The north-eastern shoreline, which was probably a irregular one, lay just south-west of Gretna. Against the nort eastern shoreline gravels were deposited as a shingle beach and as tl lake waters rose sand was deposited on top of the shingles. Clays ar peats were deposited in the central parts of the lake, which was final drained by the development of the embryonic Derwent River, as s out by Hills and Carey (1949; p. 36). After a period of erosion of tl lake sediments by the Derwent, probably flowing more or less straig south-westerly through Macquarie Plains, basaltic lava was poured in the valleys carved in the lake sediments. This probably took pla much less than ten million years ago during the Pliocene Epoch (Hil and Carey, 1949; p. 36).

The source of the flows and ash showers has not yet been foun but from the consistent southerly dip of the cross bedding in the tuff some of the volcanic centres lay to the north-east, perhaps almost alor

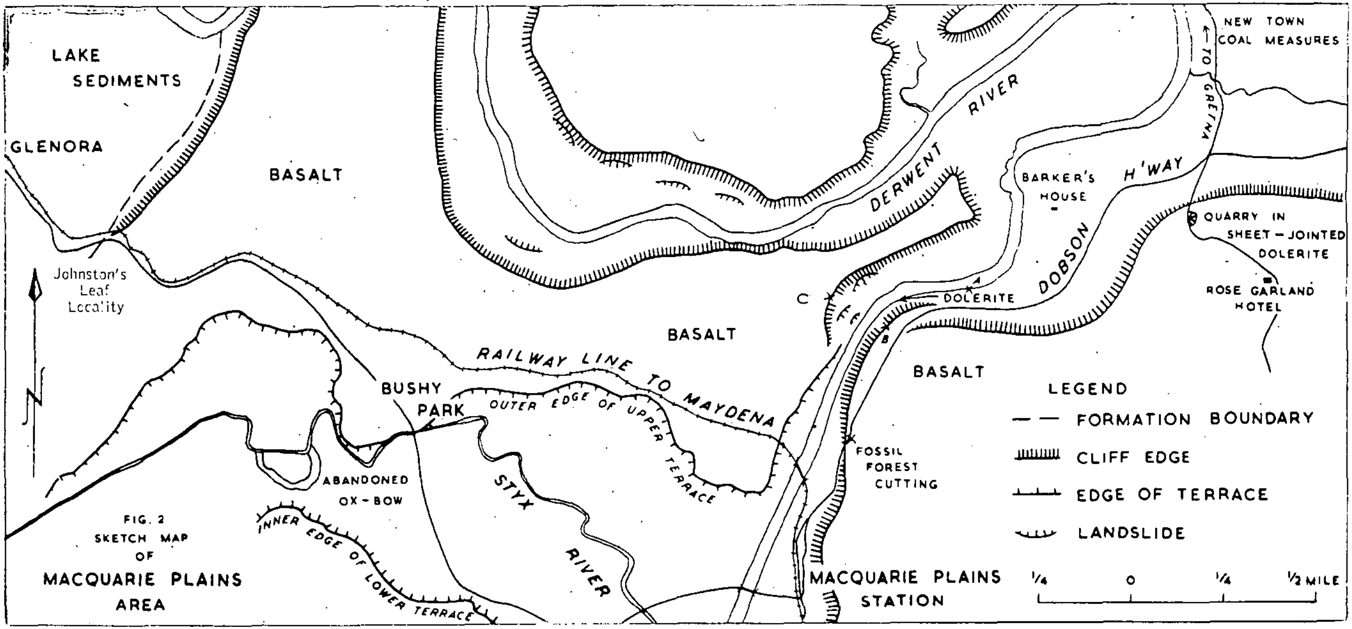

FIG. 2.—Sketch map of Macquarie Plains Area, Derwent Valley, from Glenora to Rosegarland, showing position of "Fossil Forest" cliffs.

the north eastern shore of the old lake. At least four lava flows we poured out, the third into an ephemeral lake, if one can judge from t pillow lava.

Following the pouring out of the lava after the pillow lava, a la or swamp developed on the basalt surface and sand and clay accum lated in it, together with leaves and twigs. After this lake had be drained or dried up another lava flow covered the area and anoth lake developed on the surface of this new flow. Again sand and cl were deposited and the flora of the time is partly represented by t leaves and twigs found in the sediments.

After the lake disappeared, these sands and clays became t soil, supporting a forest of cypress-like pines and probably she-oa and other trees. Marsupials roamed through this forest. This fore lived for at least 400 years and probably over 1000 years in a clima that was certainly humid and may have been monsoonal, to judge fro the incipient lateritisation of the soil. Then an explosive erupti somewhere to the north-east or north-west violently expelled a den cloud of ash over the forest. The force of the explosion knocked ov those trees growing in the area which is now the north-west bank of t Derwent, but was spent by the time it reached Macquarie Plains, that the trees were left standing but submerged in ash. Another la flow followed, and then there were several ash showers in rapid succe sion, and finally another lava flow. All told, there were at least ni eruptions in the vicinity of Macquarie Plains. Whether this was t last one in the area is not known but it seems very likely that it wa because the tops of most of the basalt covered hills form a gently slopi surface at about this level. The Derwent then began to carve dov into this basaltic plain, in places depositing gravels consisting essentia of basalt pebbles, but generally incising its original meanders into t plain until the present topography was developed.

LOCALITY INDEX

	Quadrangle	No.	Lat.	Long
Bushy Park	Ellendale	74	42°43′	146°
Glenora	Ellendale	74	42°41′	146°
Gretna	Ellendale	74	42°41′	146°
Liawenee Canal	Great Lake	53	41°52′	146°
Macquarie Plains	Ellendale	74	42°43′	146°
Plenty	Styx	81	42°44′	147°

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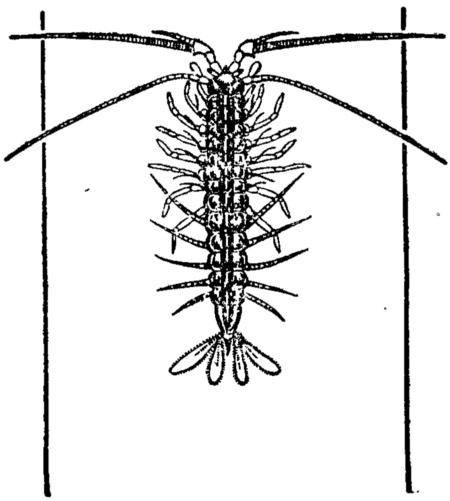
New Series, No. 6 15th JULY, 1956

Records of the Queen Victoria Museum Launceston



Edited by

FRANK ELLIS

Director of the Museum

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RECORDS OF THE QUEEN VICTORIA MUSEUM,

LAUNCESTON

Cainozoic History of Mowbray Swamp and Other Areas of North-Western Tasmania

By

EDMUND D. GILL

(Curator of Fossils, National Museum of Victoria)

and

MAXWELL R. BANKS

(Department of Geology, University of Tasmania)

7 PLATES AND 6 TEXT FIGURES

ABSTRACT

The Tertiary limestone succession in the Marrawah area includes a limestone from Green Point which contains basalt boulders and a limestone at Redpa with *Lepidocyclina* correlated with the Batesford Limestone of Victoria. Basalt overlies this limestone sequence disconformably at Mount Cameron West. A basalt at Britton's Swamp contains fragments of Tertiary limestone. Limestone also occurs near Irishtown and, in this area, basalts overly sands and lignite containing *Nothofagus, Triorites harrisii* and *Dacrydiumites*. Basalt occurs above and below "*Turritella* Limestone" at Doctor's Rocks, Wynyard. Lignite from the Launceston Beds near Evandale contains *Trisaccites* which indicates probably an Eocene or Lower Oligocene age and the lignite is overlain by basalt. Faulting at Launceston probably commenced in the Eocene or before. Basalts at Marrawah, Irishtown and Stanley were poured out into the valley tracts of streams. It is doubtful that Mount Cameron West is part of a laccolith, as has been previously suggested, and it is here considered that The Nut at Stanley is a volcanic neck.

Mowbray Swamp is underlain by an Upper Pleistocene marine sand on which rest a number of sand ridges trending E.S.E. In the swales between these ridges peat and sandy peat accumulated more than 37,000 years ago (C14 date). The peat contains the bones of *Nototherium* spp., other giant marsupials and emus, freshwater molluscs and ostracods, as well as pollens of *Banksia, Haloragis* and *Eucalyptus*. Rocky Cape Caves were probably produced as sea caves when the sea was 70 feet higher than at present and at this time the marine sand underlying Mowbray Swamp was deposited. The ancient sand ridges were formed as

sea-level fell from this height. Peat and marl formed in a swamp at Pulbeena and one of the peat samples gave an age of 13,500 years (C14 date). The holotype of *Nototherium tasmanicum* is figured. Tasmanian aboriginal rock carvings occur in Quaternary aeolianite north of Mount Cameron West and their middens occur in the dunes just south of the mountain. Duck River is incised 15 to 20 feet into its channel and is depositing a delta in Duck Bay. There is a series of Holocene sand ridges on Perkins' Island and east of the mouth of the Black River, where eighteen ridges in three sets show a total fall of about 10 feet in sea-level. The Rocky Cape Caves contain deep kitchen middens from which many fish bones and a bone awl were obtained, indicating that the Tasmanian Aborigines ate fish and used bone implements.

INTRODUCTION

During May and June of 1952 the authors spent a week in the Smithton area collecting samples for radiocarbon dating and data on the occurrence of *Nototherium* as well as investigating other problems in the Cainozoic history of the north-western part of the State. Later, Gill spent a week in the Queen Victoria Museum examining their collections. Early in 1955, Banks visited the Wynyard and Marrawah areas to check on the ages of some of the basalts.

ACKNOWLEDGMENTS

Many people have contributed directly and indirectly to this paper and to some extent the authors have acted as observers and co-ordinators of results from many sources.

Our work in the field was greatly reduced by help generously given by Mrs. E. C. Lovell and family, Mr. F. S. R. Shoobridge and Mr. B. Edwards of Mella. Mr. J. Loveday, C.S.I.R.O. Soils Division, told one of us (M.R.B.) of the probable occurrence of early Tertiary basalt at Wynyard and helped to check this point in the field. Our work at Irishtown was considerably aided by the guidance of Mr. Roy Quilliam. Mr. A. Walker, Smithton, sent specimens of basalt with limestone inclusions from Britton's Swamp to E. D. Gill. In the Evandale area Mr. K. R. von Steiglitz guided us to the spot near Evandale from which "cycad cones" had been collected.

Dr. M. F. Glaessner, Mr. A. C. Collins and Mr. A. N. Carter have all provided identifications of foraminifera collected together with comments on their age or ecology. Miss Hope Macpherson identified the shells in the marl and mound spring deposits at Smithton and in the middens at Rocky Cape; Mr. Gilbert Whitley identified the fish bones from the middens. The wood from the peat in Mowbray Swamp was identified by Mr. H. D. Ingle, C.S.I.R.O., Forest Products Division, and Dr. Isabel Cookson identified the pollens. Dr. A. W. Beasley, National Museum of Victoria, commented on the mineralogy of the marl from Mella and checked observations on the tuff from Circular Head. Mr. P. Garrett and Miss P. Reynolds, Public Library of Victoria, checked on comments in Captain Cook's log on the eating of fish and use of bone implements by aborigines. Mr. G. Baker kindly cut a slide from the Britton's Swamp material. Mr. G. D. Hubble, provided helpful information on soils (see appendix). The work originated with a request from Dr. E. S. Deevey, Director of the Geochronometric Laboratory at Yale University, for material for radiocarbon analysis and he did four analyses recorded herein. To all these people we acknowledge our indebtedness.

LOCALITY MAPS OF N W COAST, TASMANIA

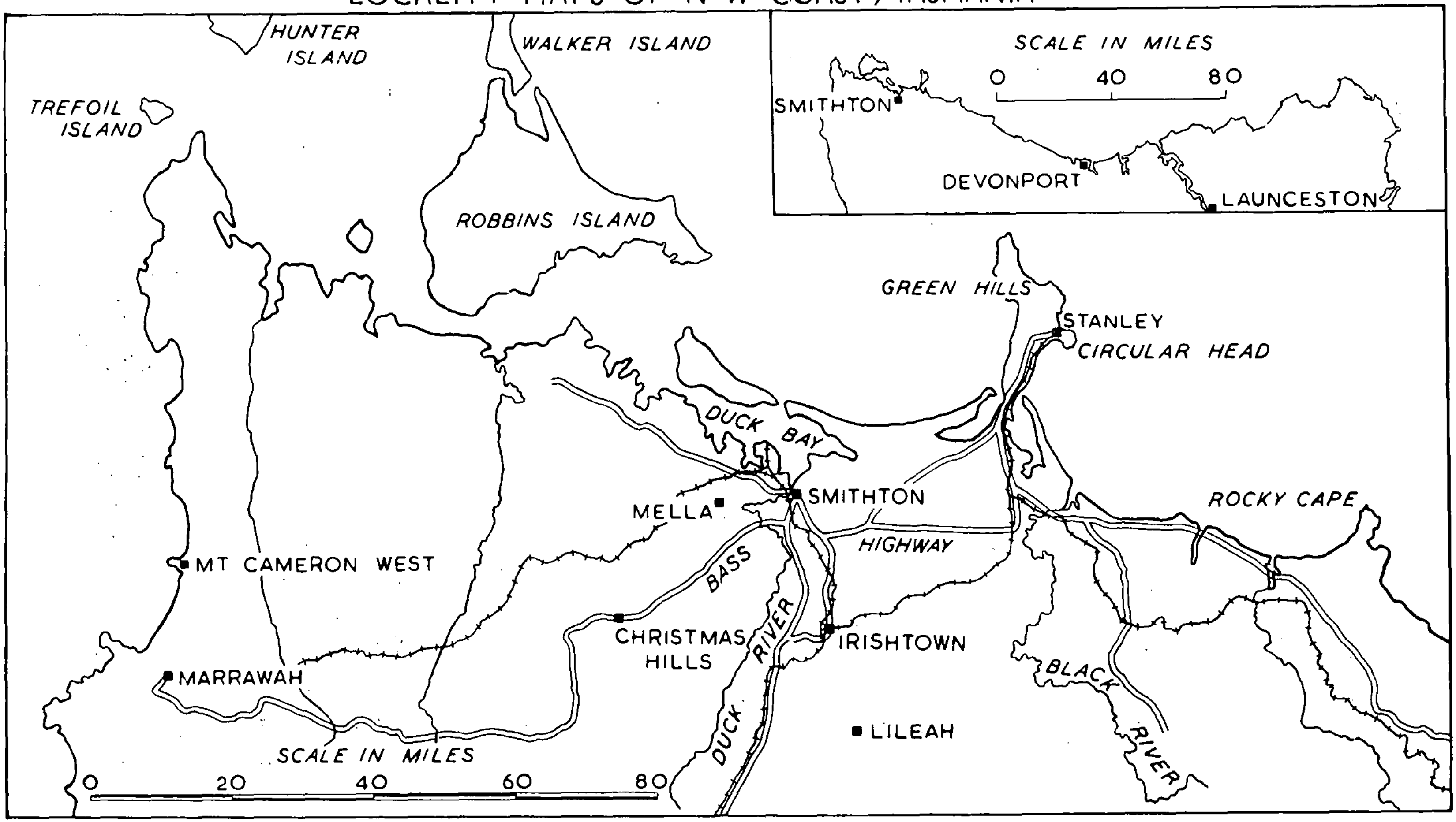


FIG. 1.

We also wish to acknowledge with thanks permission of the Surveyor General to publish the air photos of Rocky Cape, the permission of the Smithton Harbour Trust and the Mowbray Swamp Drainage Board to use and publish parts of their charts. Finally, we would like to thank Mrs. I. Mead, formerly Director of the Queen Victoria Museum, for making available collections and other facilities at the Museum.

TERTIARY SYSTEM

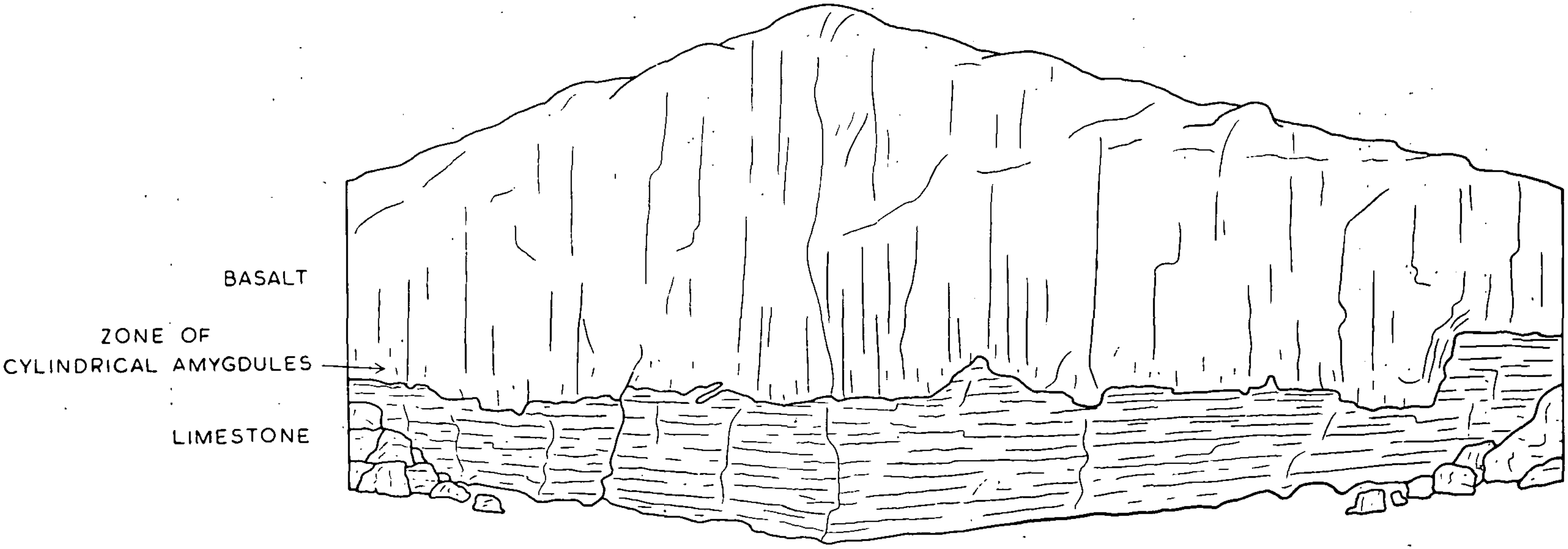
Marrawah

Tertiary limestone is widespread in the Marrawah district as shown by Nye (1941) who considered that at least some of them were younger than the basalts in the district. This was based on evidence of basalt boulders in limestone (Nye and Blake, 1938) and on the impression that the limestone fringed the basalt hills.

In an endeavour to check on this evidence, one of the authors visited the district. In a small quarry 38 chains south-east of the tip of Green Point, on the east side of a road to a farm house, bryozoal limestone was found with several angular fragments of weathered basalt. The basalt showed no sign of epidote, an almost universal constituent of the Cambrian spilites of Tasmania and is probably Tertiary. Petrological work will be necessary to prove this. This limestone is higher than that at Mount Cameron West. The precise age is not yet known but it is probably not younger than Middle Miocene. Thus it is probable that there were pre-Middle Miocene basalts at Marrawah and possibly they were pre-Upper Oligocene.

Several miles south of Redpa, near the western margin of the plain of the Welcome River, Nye (1941, p. 14) recorded a limestone sequence 100 feet thick overlying dolomite unconformably at about 135 feet above sea-level. The sequence is overlain by basalt in the surrounding hills. It has recently been shown to contain a bed of friable foraminiferal limestone with *Lepidocyclina* (*Trybliolepidina*). This is correlated with the Batesford Limestone of Victoria of Lower Miocene age. Details of these observations in the Marrawah area will be published elsewhere, but this summary is provided so that the chronology of the north-west can better be evaluated.

Edwards (1941*b*), described the basalt of Mount Cameron West as a laccolith intruding into " flat-lying (?) Permo-Carboniferous sediments ". The strata underlying the basalt were examined on the southern flank of the Mount at and just above sea-level, where they consist of yellow, white and red limestone with flaggy to massive bedding. The rock is friable, consisting almost exclusively of the calcareous remains of marine invertebrates, particularly bryozoa, so is best named a calcarenite, most of the fragments being clastic and of sand grade. Macrofossils include lamellibranchs (*Spondylus, Pecten*), brachiopods (*Magellania*) and echinoids. Foraminifera include *Carpentaria rotaliformis* Chapman and Crespin, *Cassidulina subglobosa* Brady, *Cibicides* close to *ungerianus* (d'Orbigny), *Notorotalia* probably *howchini* Chapman, Parr and Collins, and cf. *Pseudogaudryina crespinae* Cushman. Mr. A. C. Collins considered that the most probable age is Balcombian (in the wide sense). Dr. Glaessner also kindly examined a sample and reported, " I consider the fauna as late Oligocene, related to the upper part of the Torquay Group and its equivalent in South Australia. It does not contain the restricted pelagic species of the Lower Miocene Balcombian (*Austrotrillina* Zone) or the Upper Eocene (*Hantkenina* Zone)." Taken together, the reports suggest a Longfordian age, but this needs further investigation. Crespin (1945) has reported



Block Diagram Showing Contact Between Tertiary Limestone and Basalt on South Side of Mt. Cameron West

FIG. 2.

Longfordian limestone from King Island in Bass Strait. A point of interest recorded by Nye (1941, p. 14), is that the base of the limestone south of Redpa is at 135 feet. This seems to indicate that the limestone transgressed over a fairly uneven surface because it extends to below sea-level at Mount Cameron West. Another point of interest is that the limestone is often as high as 250 feet above sea-level. This probably means that the sea was that much higher in the Mid-Tertiary but, until detailed field work is done, the possibility of faults having elevated both base and top cannot be overlooked.

The basalt overlies the limestone with a marked disconformity as can be seen in the cliffs to the south of Mount Cameron West. The disconformity surface is quite irregular and indicates some considerable period of erosion between the deposition of the limestone and the outpouring of the basalt. This surface is shown in the block diagram (text-figure 2). The only effect of the basalt on the limestone is the hardening of the latter to a depth of a few inches. Near the contact the basalt is very fine grained, almost tachylytic in places, and is remarkable for the long cylindrical (pipe) amygdules, generally one quarter to one half of an inch in diameter, filled with calcite, which rise six inches to a foot above the contact. These amygdules attain a maximum diameter of three quarters of an inch; some are simply branched but most are solitary pipes. These indicate that the basalt cooled at the surface of the earth, or very close to it.

The basalt of Mount Cameron West extends in an unbroken ridge eastwards to the main basalt plateau and neither the field occurrence of the basalt, nor its relation to the sediments, requires the postulation of a laccolith, but agrees well with the idea that it is simply a thick flow or series of flows. In the cliff at the south end of Mount Cameron West, moderate columnar jointing can be seen in the basalt, some of the columns being over six feet in estimated diameter. The columns seem to indicate that there was but a single thick flow. It appears likely that Mount Cameron West is a remnant of a dissected flow which originally poured down a valley running approximately west to the position of the Mount. The presence of such a valley seems indicated by the various heights of Tertiary limestone outcrop as recorded by Nye (1941). Thomas (1945) reported that "It is extremely doubtful whether Mount Cameron West is a laccolith, as although the main peak may be considered as a plug, the two small peaks are composed of basalt flows, resting on the denuded flanks of the Miocene limestone." It is very difficult to reconstruct a sufficient cover of Tertiary sediments in the area to halt the upward progress of the basaltic magma in order to produce a laccolith and on this count too it seems likely that the basalt is extrusive.

Observations at Marrawah thus indicate that basalts were possibly erupted before the Upper Oligocene, that limestone was deposited during the Upper Oligocene and Lower Miocene and that these were probably eroded to form valleys up to 200 feet deep before basalt covered them. The upper basalts are therefore younger, possibly considerably younger, than Lower Miocene.

The vertical nature of the cliff at the south end of Mount Cameron West is due to the erosion by the sea of the Tertiary limestone at its base, thus causing collapse of the columns of basalt above. This is not a rapid process however, as there is an aboriginal kitchen midden among the boulders of the talus slope lying against the limestone at the foot of the cliff, and the aborigines have not lived in that area for over 75 years.

Basalt from the north end of Britton's Swamp contains pieces of baked fossiliferous Tertiary limestone, with *Pecten* cf. *antiaustralis*, a piece of pyrite-bearing Palaeozoic sedimentary rock and pieces of opaline silica. The limestone is highly fossiliferous and contains *Carpentaria, Triloculina, Sigmoilina* and other Miliolid genera. Unfortunately there was insufficient evidence for an age determination and Mr. Carter suggested that ". . . possibly metamorphism destroyed all the small hyaline foraminifera. The association of *Carpentaria* with abundant Miliolids suggests a shallow water deposit." The basalt tends to follow the outlines of the fossils and a bryozoan can be recognized in the basalt which has digested the limestone matrix. This occurrence is of interest in indicating that Tertiary limestone occurs well inland in this district.

Lileah and Irishtown

Thomas (1944) recorded Tertiary limestone from near Irishtown but did not state precisely where.

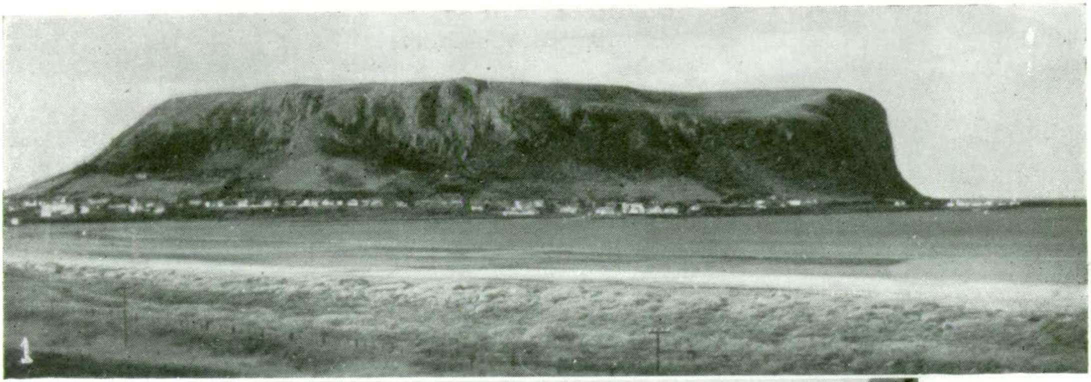
On the basaltic plateau east of Irishtown (south-east of Smithton), a tunnel, 3 chains long, has been excavated in Tertiary deposits under basalt on R. V. McKay's farm (Smithton, Run 4, No. 30, 809; 6·6 cm. N.W. of C.P.). Three feet of lignite were observed covered by carbonaceous sand then clayey sand. Samples of wood and carbonaceous sand were collected. The former proved on sectioning to be too collapsed for identification. Pollens occur in the carbonaceous sand and include:

Nothofagus (*brassii* type)
Nothofagus sp. *a* (*menziesii* type)
Triorites harrisii Couper (perhaps the most numerous type)
Myrtaceidites parvus anesus Cookson and Pike
Myrtaceidites mesonesus Cookson and Pike
Podocarpus sp.
Dacrydiumites florinii Cookson and Pike
Dacrydiumites mawsonii Cookson
cf. *Polypodium* (fern)
Smooth trilete fern spore.

This Tertiary flora disappeared from S.E. Australia by the end of the Pliocene (Gill, 1952).

At Lileah, in a creek bed south of a house (Aerial photo Smithton Run 2, No. 30,913; 5·4 cm. S.W. of C.P.), lignite occurs, covered by a partly silicified sandstone, which is light yellowish brown to reddish brown in colour due to ferruginization. Some nodules of limonite were noted. Two geochemical processes are represented here which must have taken place at different times because of the different pH conditions involved. It is probable that the silicification took place first and the ferruginization later, during the weathering of the basalt. The lava is very deeply weathered, nine to ten feet of dark red loam being visible in the road cuttings. Its physiographic occurrence and degree of weathering are reminiscent of the Older Basalt of Victoria, New South Wales, and Queensland. The lignite contains milky quartz gravel in places. Wood from this bed proved to have its cells too collapsed for identification and no pollen was found in the sample collected for pollen analysis.

Nye, Finucane and Blake (1934) have shown that the basalt in this area was erupted as four flows to a total thickness of over five hundred feet and that between the flows are deposits of quartzites, gravels, sandstones and clays with one lignitic formation. These authors suggested that presence of a pre-basaltic valley "trending east-north-easterly from the vicinity of the Arthur River, through Trowutta, towards the Stanley Peninsula" where it is probably represented by the basalt of the Green Hills. The existence of this pre-basaltic river was also thought probable by Edwards (1941*a*) who also deduced valleys entering the main



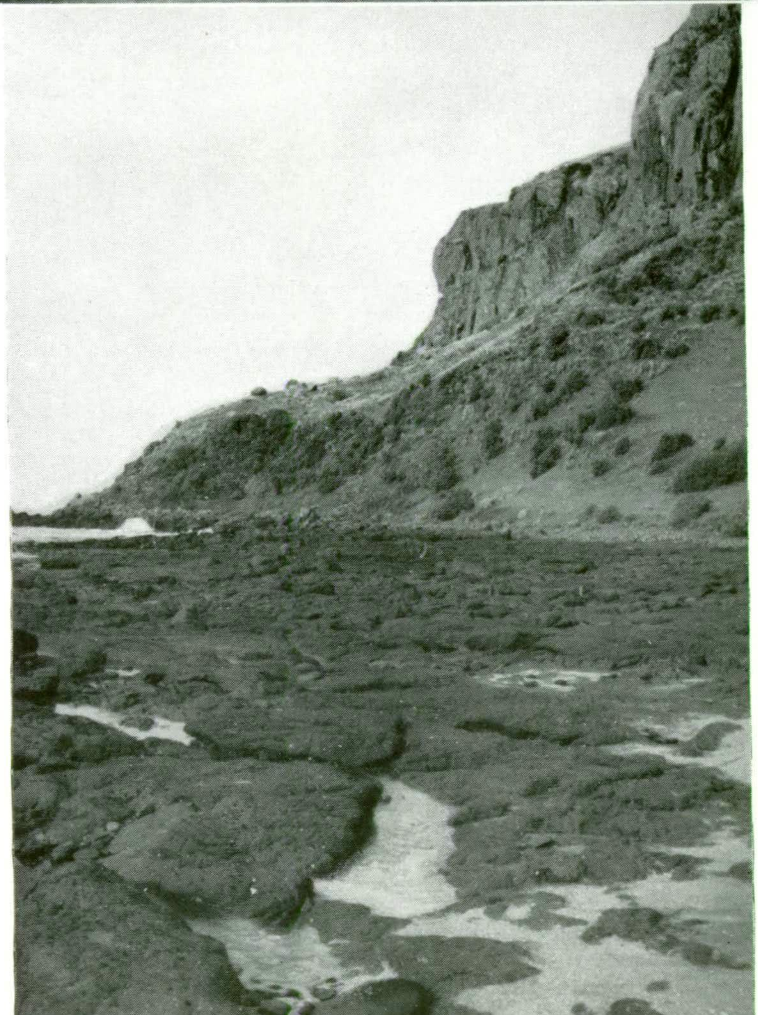


PLATE VII.

FIG. 1.—General view of The Nut, Stanley.

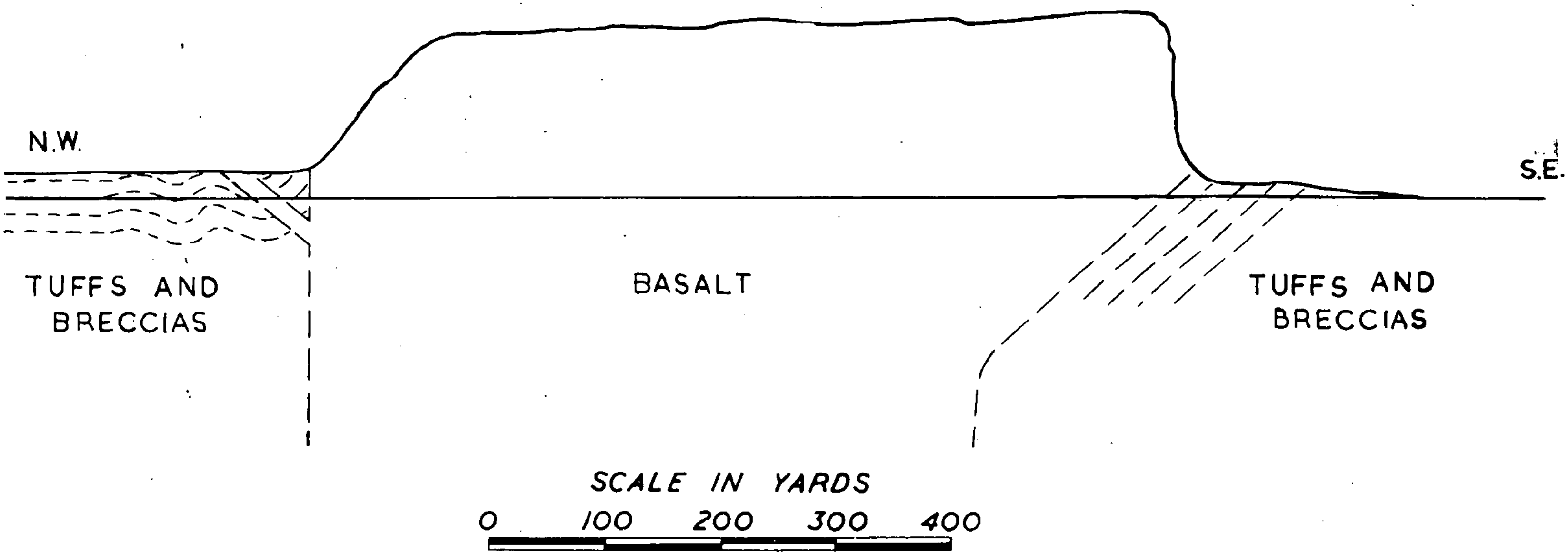
FIG. 2.—Shore platform of basaltic ejectamenta near the Stanley cemetery. Part of The Nut can be seen in the background.

one from the east near Circular Head. The sandstones and conglomerates of the inter-basaltic formations were probably derived from the Bryant Hill Quartzites (Carey and Scott 1952), which would have formed the sides of the fossil valley, the topography covered by the basalt had a low relief with gentle slopes as shown by the relative heights of the base of the basalt. A rough average gives the gradient of the former valley floor from Edith Creek to the sea at Green Hills as 25 feet per mile, while from Edith Creek to Irishtown the grade was about 50 feet per mile.

Circular Head (Plate 7)

Circular Head is a prominent topographic feature of the far North-West coast of Tasmania. It has been described as a crinanite laccolith by Edwards (1941*b*) who wrote, " On the north-western side, on the beach below the Stanley cemetery, the scree overlies soft mudstones and grits which are exposed in the wave-cut bench. These sediments . . . are presumably of Permo-Carboniferous age ". The rocks in the shore platform near the cemetery were examined and also those on the south side of The Nut, in a quarry behind the wharves. According to Edwards, they also outcrop on the northern end of Godfrey's Beach where they are overlain by basalt, but this exposure was not examined. The rocks near the cemetery are volcanic ejectamenta of all sizes from fine tuff to breccia, most being coarse tuff. Brownish in colour and very porous, they seem generally to be rather decomposed. They are finely laminated to massive, although in places the bedding surfaces of the tuffs in contact with the breccias are most irregular. Cross bedding is also present, but insufficient observations were made to determine if this was of aeolian or aqueous origin. The dip of the beds varies from steeply dipping to the north to almost horizontal and in general the dip seems to steepen as the inferred contact with the igneous rock is approached. Detailed mapping will be necessary to show the structure. In the field it appeared that the rock was composed of irregular, angular and subangular fragments of volcanic rock in a finer-grained matrix. Occasional angular fragments of massive and laminated quartzite were also found.

The disintegration of the rock in the laboratory confirmed the observations made in the field. The rock was sufficiently friable to break down after standing in water for a few minutes, after which the sediment was graded and each grade examined separately. All grades were composed dominantly of angular to sub-angular grains and sub-rounded grains were the exception. The coarser grades were composed almost entirely of vesicular and amygdaloidal basalt and tachylyte, while the finer grades were similarly constituted with the addition of fragments of olivine, pyroxene, and the white mineral that fills the amygdules. An independent examination of the heavy minerals by Dr. A. W. Beasley proved the presence of basaltic minerals. Thus, there can be no doubt that the rocks are tuffs and breccias of pyroclastic origin. Fossils were not observed in the brief examination made in the field, nor was any sign of fossils seen in the rocks when studied in the laboratory. Thus the age of the sediments cannot be satisfactorily determined. The authors consider, however, that it is most unlikely to be " Permo-Carboniferous ". The rock is very poorly lithified whereas all Permian rocks seen by the authors in Tasmania are well lithified and require very harsh treatment for their disintegration. On the other hand, the Circular Head rocks resemble closely the tuffs and breccias associated with the Tertiary basalt flows in Tasmania and Victoria, and so the authors prefer to regard them as Tertiary.



SKETCH SECTION THROUGH THE NUT, STANLEY

Fig. 3.

The basic igneous rock intrudes these sediments somewhat irregularly. In the quarry face on the south-east side of The Nut, the contact is concordant and steeply dipping to the north and north-west. On the shore platform to the north of The Nut, several dykes of basalt occur in the sediments being roughly at right angles to the inferred contact between the basalt and the sediments. In several of these dykes the basalt is seen to be vesicular and Edwards (p. 408) pointed out that the basalt just above the contact on the south-east side of The Nut is also vesicular. The vesicularity suggests that the basalt consolidated at the surface, or closer to it than envisaged by Edwards, while the contacts observed and the structure of the sediments as far as seen do not support the idea that The Nut is a laccolith. Rather do they suggest that it is the remnant of a volcanic neck intruded through tuffs, probably of Tertiary age. Further field work and mapping are necessary before this idea can be finally substantiated.

Doctor's Rocks, Wynyard

At Doctor's Rocks, east of Wynyard, a flow of basalt overlies the Permian Wynyard Tillite unconformably and passes below sea-level. This basalt shows no sign of pillow structure at either the lower or upper contact so that from available evidence it would seem to have been poured out onto the land surface. The basalt is overlain by some feet of "*Turritella* Limestone", as developed at Fossil Bluff, Wynyard and where the limestone overlies basalt the basal few inches contain basalt boulders. This limestone is in turn overlain by more basalt. The limestone is Oligocene (Janjukian), so approximately there is a pre-Oligocene basalt and a post-Oligocene basalt. The discovery of the limestone between the basalt flows was made by J. Loveday, C.S.I.R.O. Soils Division, and will be more fully described elsewhere.

Evandale.

Mr. K. R. von Steiglitz kindly conducted us to Rose Rivulet, Evandale, near Launceston. Clays, clayey sands, sand and ironstones outcrop in the banks of the creek. They are Tertiary in age and belong to the palaeogeographical Lake Tamar (Carey 1947). From this site came the specimens considered by H. H. Scott (1931, 1934) to be Cycadophytes. They were collected by Mr. von Steiglitz and Mr. E. O. G. Scott, so we were guided to the locality by one of the original collectors. One of us (E.D.G.) later examined Scott's specimens in detail and could not find justification for this determination, an opinion supported by Dr. Isabel Cookson (1953). Carbonaceous material from this site was kindly examined for us by Dr. Cookson, who recognized the following pollen forms:

Nothofagus (*brassii* type)
Nothofagus sp. *c.* Cookson
Nothofagus sp. *g.* Cookson
Banksiaedites spp.
Beaupreaidites verrucosus Cookson
Proteacidites cf. *crassus* Cookson
Proteacidites parvus Cookson type
Myrtaceidites spp.
Myrtaceidites parvus Cookson and Pike type
Microcachrydites antarcticus Cookson and Pike
Podocarpus several types
Dacrydiumites florinii Cookson and Pike
Trisaccites micropterus Cookson and Pike

On present knowledge, the last-named sporomorph is pre-Yallournian in age. In spite of all the work done on the Yallourn brown coals, no *Trisaccites* has yet been found in them, whereas the sporomorph is common in the Eocene brown coals of the Otway Mountains (also in Victoria) which present a similar facies. *Trisaccites* is not known to exist later than the Eocene (or Lower Oligocene at most). It is found in the sub-Older Basalt deposits of the Snowy Mountains and Vegetable Creek in New South Wales, which are probably of similar age (Cookson and Pike 1954).

This dating is very significant, because it allows some of the faulting of the Launceston area to be dated. Carey (1947) showed that the sequence of events in the Launceston area was: dolerite intrusion, peneplanation with lateritization, faulting, deposition of sediments in lakes developed in the fault troughs and then eruption of basalts. Some of the lake sediments can now be dated as Eocene or Lower Oligocene so that the earlier faulting occurred in the Lower Tertiary. Faulting has displaced some of the lake beds, as seen in the excavations for the Trevallyn Power Station and it is likely that faulting continued during deposition. The faulting is not known to have displaced the basalt which overlies the lake sediments probably disconformably and the valley occupied by the basalt near Beauty Point has been cut by the Tamar Valley. The latter can be traced by examination of submarine contours to a depth of 125 feet below sea-level. The erosion of the valley to this depth is thought by Edwards (1941*a*) to have occurred during a period of low sea-level, correlated with the Mindel Glaciation. The basalt then is post-Lower Oligocene and pre-Middle Pleistocene. No closer estimate can yet be made. Cotton (1949, p. 293) doubted the antiquity of the faulting around the Launceston trough on geomorphological grounds and tended toward an Upper Tertiary age for them. If the argument based on *Trisaccites* is correct, however, much of the faulting must be Lower Tertiary, even older than the Lower Miocene age postulated by Carey (1947) and criticised by Cotton. The possibility of Upper Tertiary faulting cannot yet be ruled out but it is remote. The main scarp-forming faulting is probably Eocene in age.

Summary of Observations on the Tertiary System

In the Lower Tertiary (Lower Oligocene or before) faulting commenced to disrupt a lateralized peneplain in the Launceston area. Gravels, sands, clays and lignite with *Trisaccites* were deposited in a fault trough, with faulting continuing during deposition. The climate was apparently pluvial and perhaps warmer than at present. In the Wynyard districts basalt was poured out, probably before the Upper Oligocene, on to a land surface extending below present sea-level and basalt was possibly erupted in the Marrawah district before the Upper Oligocene. At Wynyard, the Lower Tertiary basalt was covered by marine Lower Miocene limestone and at Marrawah by marine limestones of Upper Oligocene to Lower or perhaps Middle Miocene age. Similar limestones to those at Marrawah occur also at Temma, Britton's Swamp and Irishtown up to heights of 250 feet above sea-level, probably marking extensive marine transgressions in the Miocene. Later the sea retreated to below its present level, the limestones were eroded to produce fairly wide valleys several hundreds of feet deep. Sands, gravels and lignites accumulated in these valleys as in the Lileah and Irishtown area. The limestones were deposited in a sea warmer than at present (as shown by the presence of *Lepidocyclina*) and the lignites indicate a pluvial climate, probably a little warmer than at present. Basalt flowed down these valleys cut in the limestone to below present sea-level. This seems to be the case at Marrawah, Britton's Swamp and Montagu, Irishtown and Circular Head and Wynyard. There were apparently many eruptions of lava as Nye et al. (1934) recorded at least four, separated by sands and lignite at Irishtown, and the basalt of Green Hills flowed down a valley system cut in tuff from earlier eruptions. The volcanic neck of The Nut is later than the tuffs but its relationship to the flows of Green Hills is unknown. The age of the basalts at Launceston is not known with certainty but the limits are Lower Oligocene and Middle Pleistocene.

QUATERNARY SYSTEM

PLEISTOCENE SERIES:

Christmas Hills

The road from Smithton to Marrawah passes over a slightly higher and much more sandy area of the Mowbray Swamp as it approaches the Christmas Hills. Where the road ascends from the Swamp to the higher country, cuttings reveal a formation of fine white sand. An instructive section can be seen in a quarry on a prominent bend one to three chains east of Marrawah 26 milepost (Aerial photo Smithton run 5, No. 30,786).

The sequence is as follows:

Top	1 ft.	mid-grey soil
	10 ft.	white sand (mostly clear quartz)
Bottom	6 ft.	plus of dark-brown carbonaceous sand.

The sand is very fine, well rounded, and well sorted. Both the white sand and the carbonaceous sand are cross-bedded (Plate 4, figs. 1-2), the latter having a persistent dip of 27° West and a meridional strike. The nature of the sand and the cross-bedding indicate that the materials were windblown. The carbonaceous sand lenses out at the east end of the quarry, but is still well developed where the outcrop is cut off at the west end 1½ chains away. It occurs also in the gutter of the road. Further up the hill, white sand occurs over the red clay which characterizes the plateau above. The red clay is derived from rocks of basaltic type.

Three periods of differing recent climatic conditions are suggested by the sands on the flanks of the Christmas Hills, viz.—

Pluvial	Formation of carbonaceous sand as seen in bottom of quarry.	Carbon rich.
Drier	Formation of white sand deposit.	Carbon poor.
Pluvial	Formation of present carbonaceous soil and thick forest growth.	Carbon rich.

Mr. G. D. Hubble, C.S.I.R.O. Division of Soils, has drawn our attention to the possibility that this section (and the one at Chequers Drain) is a giant podsol and not a series of layers produced by different climatic conditions.

The present average rainfall of the area varies at different localities from 34·92 ins. to 57·39 ins. per annum, the higher falls occuring in the higher parts of the country. Dr. Isabel Cookson examined the carbonaceous sand from the bottom of the quarry, and found the following pollen and spores:

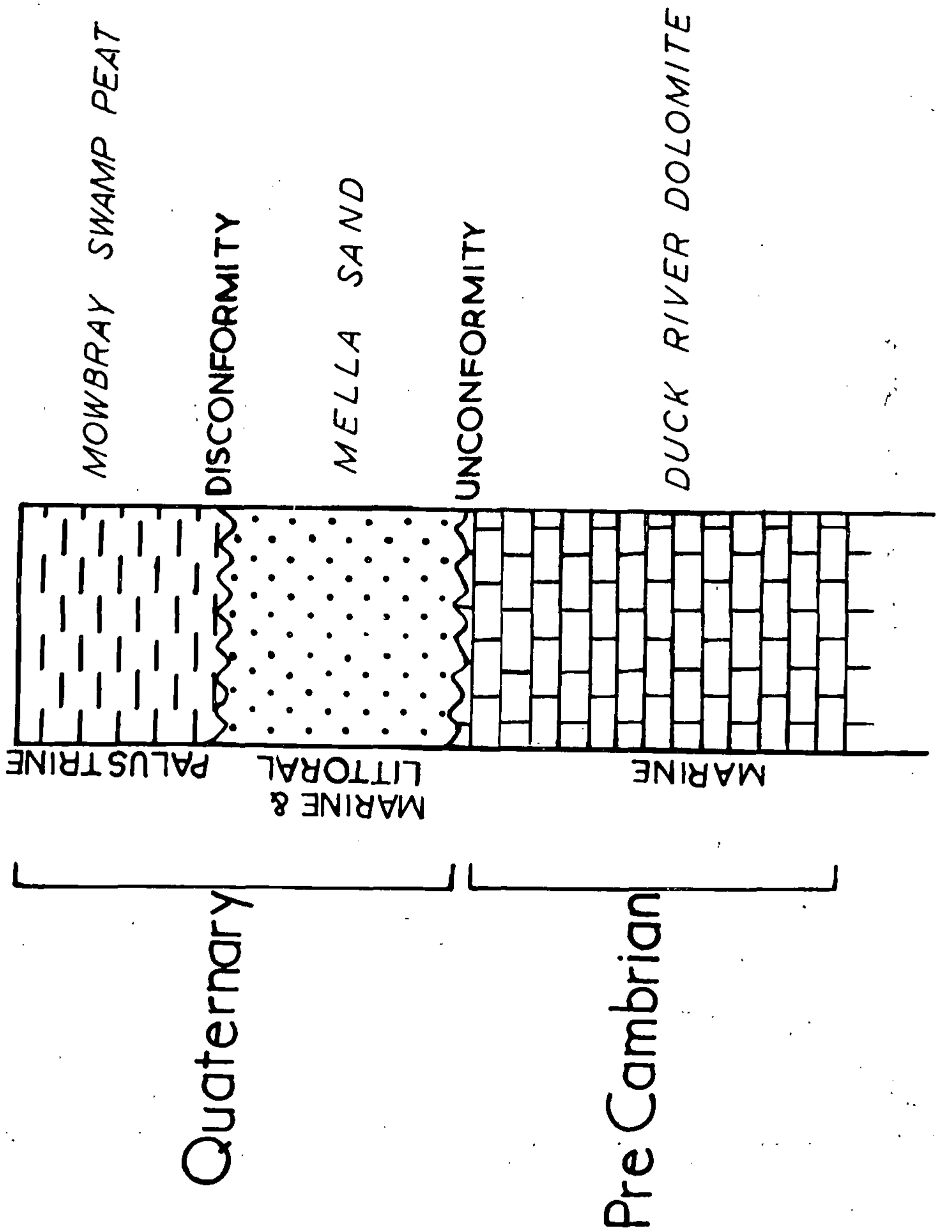
Myrtaceae
? *Podocarpus alpinus*
Compositae
Gramineae
cf. *Gleichenia*.

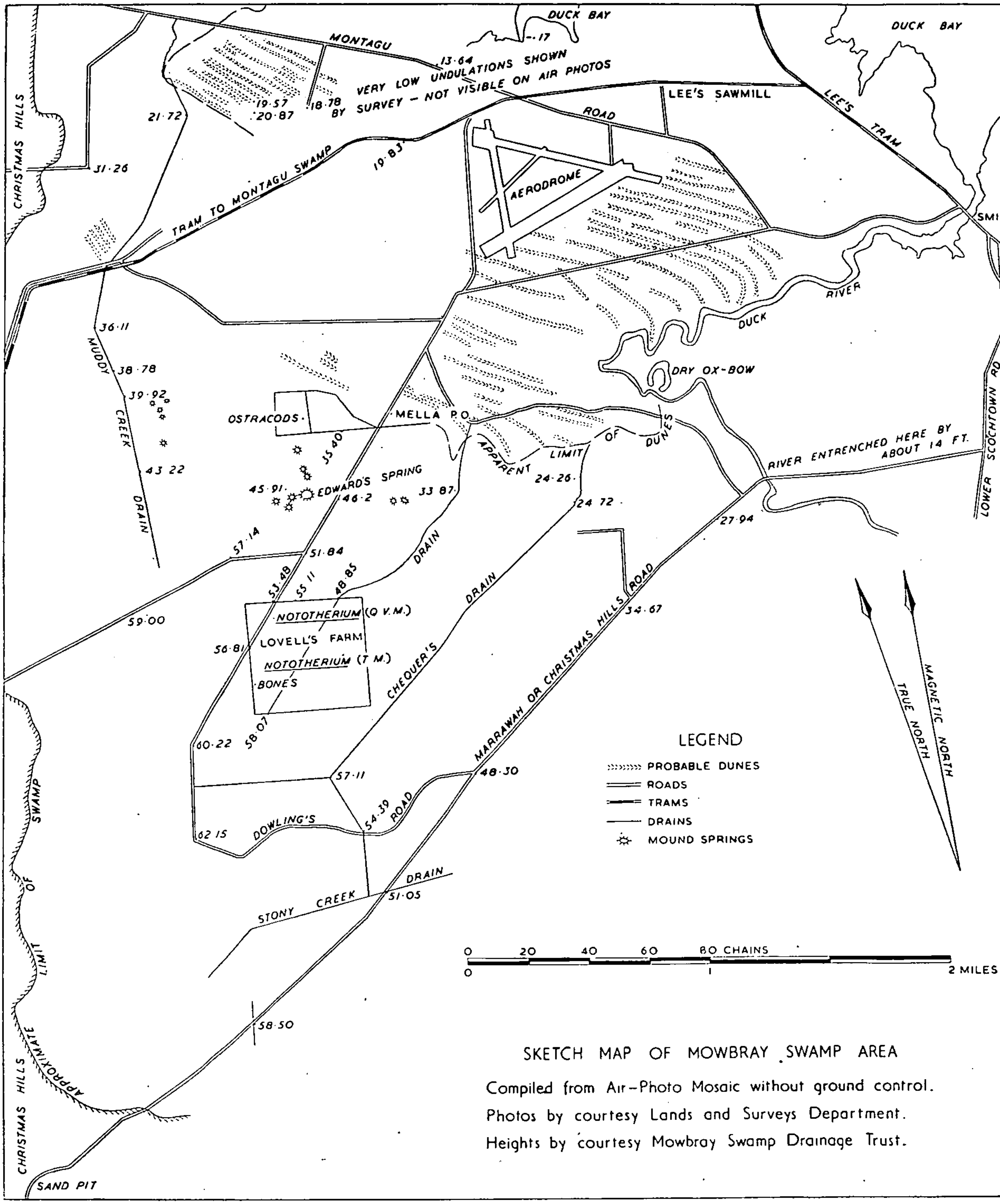
PLATE IV.

FIG. 1.—Quarry on south side of Marrawah Road at Christmas Hills.
FIG. 2.—Closer view of the polleniferous carbonaceous sand.

Nye, Finucane and Blake (1934) and Edwards (1941*a*) have commented on the sand deposits of the Christmas Hills in relation to the Duck River Plain. Our observations support the view that the present level of the plain is more or less the original one.

FIG. 4.





SKETCH MAP OF MOWBRAY SWAMP AREA

Compiled from Air-Photo Mosaic without ground control.
Photos by courtesy Lands and Surveys Department.
Heights by courtesy Mowbray Swamp Drainage Trust.

Mowbray Swamp

South and west of the town of Smithton is a lowland some six miles wide and extending twelve miles inland. On the east it is bordered by land of the order of 200 feet above the sea, consisting of folded Cambrian spilite and Precambrian silicified sandstones covered on the seaward part by sands and further inland by Tertiary basalt (Carey and Scott 1952). On the west, the lowland is bordered by similar high ground underlain by ?Cambrian argillite, greywacke and breccia, as may be seen, for example, in a quarry on the Montagu Road and by the coastal outcrops at Stony Point. The eastern side of the lowland is underlain by Precambrian dolomite, but what underlies the main part of the Mowbray Swamp is not known. The lowest bed of the Pleistocene Series so far found beneath the Mowbray Swamp is a sand—here called the Mella Sand and defined as a formation of sand of unknown thickness underlying the Mowbray Swamp Peat, exposed at Lovell's Farm, Mella. Nye, Finucane and Blake (1934) reported marine mollusca from Mowbray Swamp, probably from the Mella Sand. In the National Museum of Victoria, Melbourne, there is a collection made from Mowbray Swamp by Mr. L. R. East, consisting of the following:

Cardium racketti Donovan; a sand dweller, and still common along the coast;
Ostraea sinuata Lamarck; the rock oyster;
Panopea australis Sowerby; a mud dweller;
Mimachlamys asperrimus (Lamarck); a deep-water dweller.

These shells represent a mixture of facies, and so must have been washed together at their place of fossilization. On the farm of Mr. F. S. R. Shoobridge, in a drain 370 yards north-west of the Mella Road, opposite the Mella Post Office (see text-figure 5), casts of *Cardium* were found in peaty sand dug from the bottom of the drain about four feet from the surface. Reports of a number of other occurrences of sea-shells under the peat were received, but the shells were not seen. No evidence was seen of Pleistocene marine sediments on the high country east and west of the lowland. The sand constituting this formation may have been derived from the breakdown of the Precambrian Bryant Hill Quartzite as can be seen clearly in the White Hills, south-east of Smithton. A quarry south of the highway shows the rock to be leached for ten to twenty feet from the surface, freeing the sand; so much so that the ridge looks like a sand dune. This hill is not within the present drainage area of the Duck River, however, and if the present eastward set in Bass Strait was operative at the time of the high sea-level when this formation was deposited, sand from White Hills could not have been deposited in the former Duck Bay.

The marine part of the Mella Sand is overlain by a number of sand ridges, now occurring at Lovell's Farm House, Mella, and at other places in Mowbray Swamp as shown on the map, figure 5. The ridges are now low sand rises spaced 80 to 100 yards apart and trending in an E.S.E. direction probably parallel with the former shore lines. The ridges become progressively lower in elevation above the sea as the present shore line is approached. Mowbray Swamp is highest in the south-west where sand is accumulated in the lowland, and on the sides of the Christmas Hills. The ground here is about 64 feet above H.W.M. (as shown on the Drainage Board Map) but there may be a small depth of sand accumulated by wind action at the foot of Christmas Hills.

The most interesting formation is the Mowbray Swamp Peat. This is a formation of peat and some intercalated marl, usually less than 7 feet thick but exceptionally over 15 feet thick, developed over most of Mowbray Swamp area, and containing fossils including *Nototherium, Palorchestes, Limnicythere,* &c. It is Upper Pleistocene in age.

Drain sections and ten spade and auger holes in the Mella District and south of Smithton proved peat from 1′ 6″ to 7′ deep. The only exception noted was a comparatively large cutting in the Chequer's Drain S.S.W. of Smithton (text figure 2; aerial photo Smithton run 7, no. 30,661, 6 cm. N. of centre point). The drain cuts through a ridge into the Duck River, and reveals:

Thin soil at surface with *Eucalyptus* and tea-tree;
4-5 ft. fairly loose white siliceous sand;
8 ft. 6 ins. compact carbonaceous sand measured to water level: the top of this bed is horizontal;
Seven ft. more of this bed was proved by auger, but further penetration was impossible owing to the compactness of the rock.

This carbonaceous bed is therefore at least 15 ft. 6 ins. thick; it is not stratified, but has horizontal depositional structures. The succesion here is a loose white sand overlying a compact carbonaceous sand, which is the same succession seen in the Christmas Hills (p. 13). The peat and peaty sand are found in the swales of the ancient sand ridges as shown by auger hole sections in different parts of the swamps such as are recorded a little later when dealing with the *Nototherium* occurrences.

The peat contains a rich fauna and some pollens and the species known to be present are listed below. Where they have been previously recorded, the literature references are given.

MAMMALIA

Nototherium tasmanicum Scott
Scott 1911, 1915, 1927, Scott and Harrisson 1911, Scott and Lord 1921*b*, 1922, 1923, 1924, 1925*a*, *b*, 1926, Noetling 1912*a*.

Nototherium mitchelli Owen
Scott and Lord 1921*a*, *b*, *c*, 1923, 1925*a*, *b*, Scott 1927.

Palorchestes cf. *azeal* Owen
Scott 1916, Scott and Lord 1925*b*.

Phascolonus sp.
Scott and Lord 1925*b*.

Vombatus sp.

Kangaroo

Wallabies

Rodent

AVES

Dromaius diemensis Le Souef
Scott 1932.

ARTHROPODA

Candona lutea King
Chapman 1914.
Candonocypris candonoides (King)
Determined by N. de B. Hornibrook.
Darwinula sp.
Deevey 1955.
Limnicythere mowbrayensis Chapman
Chapman 1914.

MOLLUSCA

Amphipeplea subaquatilis neglecta Petterd
Chapman 1914.
Assiminea tasmanica Woods
Chapman 1914.
Bulimus dufresnii Leach (= *Caryodes dufresnii*)
Noetling 1912*a*.
Bulimus tasmanicus Woods (= *Lenameria attenuata* (Sowerby))
Chapman 1914 ?
Bythinella nigra (Quoy and Gaimard) (= *Austropyrgus nigrus*)
Noetling 1912*a*, Chapman 1914.
Helix hamiltoni Cox (= *Stenacapha hamiltoni*)
Noetling 1912*a*.
Pisidium tasmanicum Woods (= *Australpeca tasmanica*)
Noetling 1912*a*, Chapman 1914.
Simlimnaea (formerly *limnaea*) *gunnii* (Tate)
Sphaerium tasmanicum Woods
Noetling 1912*a*, Chapman 1914.
Succinea australis Ferussac (= *Austrosuccinea australis*)
Noetling 1912*a*.
Vitrina milligani Pfeiffer (= *Melavitrina milligani*)
Noetling 1912*a*, Chapman 1914, Iredale 1933.

PLANTAE

Dr. Isabel Cookson kindly made pollen analyses of samples from Mowbray Swamp and a sample of peat from between two and three feet at the radiocarbon sample site, near the locality which yielded the type specimen of *Nototherium tasmanicum* (Plates 1-2), four to five chains east of Lovell's farm house, Mella (text figure 5, loc. 2), gave the following results:

Eucalyptus sp.
Gramineae
Compositae, cf. Heliantheae
Other types not identified.
(Pollen content low).

Nototherium and Tasmania

Diprotodon, the largest marsupial known, has been found all over the Australian mainland but it did not reach Tasmania, as far as is known. It did reach King Island, however, which is in Bass Strait between the mainland and Tasmania (Keble 1945), apparently at the time of a eustatic low sea level in the Upper Pleistocene. In Tasmania itself there lived *Nototherium mitchelli* which is found also in King Island and in Victoria, but in addition there was in Tasmania the indigenous species *N. tasmanicum*. In the island of New Guinea there was likewise an indigenous species *N. watutense* (Anderson 1936, 1937). The nototheres are an ancient group going back at least to the Miocene (Gill 1953*b*), but all the above species are believed to be Pleistocene. So far, giant marsupials have been found only in the northern part of Tasmania.

Nototherium tasmanicum. Precise localities have not been published for the fossils of this species recorded from the Mowbray Swamp, but the writers were able to find local residents who witnessed the collection of certain specimens and could show exactly whence they came. The almost complete holotype skeleton (Plates 1-2) in the Queen Victoria Museum at Launceston (reg. no. 1760) with only the feet and a few other bones missing, came from Mr. E. C. Lovell's farm at Mella, 110 yards a little north of east of the house (Aerial photo 30,663, Smithton run 7, 3·9 cm. 8° N. of W. of C.P.). Mr. Lovell found the skeleton at a depth of five to six feet and excavated it himself. The locality is a T-shaped drain intersection. A spade excavation was made in the paddock beside this site to avoid the roots of trees lining the drain and peat was obtained from between 2 and 3 feet from the surface for radiocarbon analysis. Whitish sand was met at a depth of four feet (see text figure 5 for these sites). The surface of the ground here is approximately 55 feet above H.W.M. as estimated from the Drainage Board map. At the waterhole nearby (same aerial photo 3·3 cm. 6° N. of W. of C.P.), peat followed by sandy peat reaches a depth of seven feet. On the other hand, the Lovell home is on a sandy rise.

A less complete skeleton of *Nototherium mitchelli* was located by Mr. Lovell about a quarter of a mile S.S.W. of the Lovell home (locality 4; same aerial photo, 5 cm. S. of W. of C.P.). Mr. Lovell left this fossil for Mr. H. H. Scott of the Queen Victoria Museum to excavate. It is now in the Tasmanian Museum, Hobart. The drain from which this *Nototherium* came was six feet deep when excavated. Members of the Lovell family there at the time of the finding of the fossils, told us that all the fossil marsupial bones found on their property came from the *bottom* of the peat. In the Queen Victoria Museum is a piece of sandy peat "extracted from the brain case of *Nototherium tasmanicum*." The sand is a very fine well-rounded clear quartz sand. The peat nearer the surface has much less sand than this specimen. A few bones of *Nototherium tasmanicum* were found at

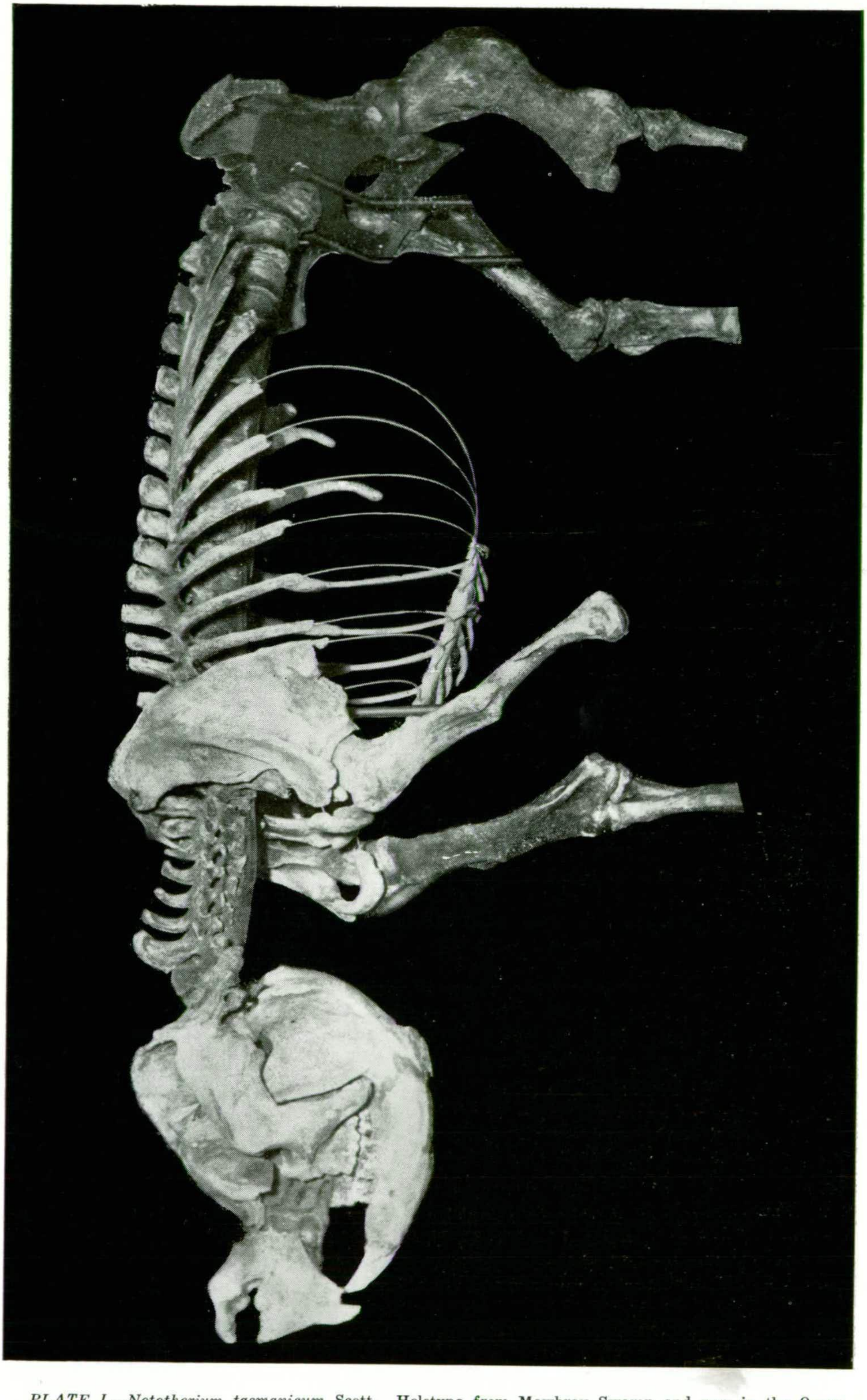


PLATE I.—Nototherium tasmanicum Scott. Holotype from Mowbray Swamp and now in the Queen Victoria Museum, Launceston. Side view of articulated skeleton.

yet another locality on Lovell's farm, on the west boundary of the property at the intersection of two drains about 22 chains from the house (same aerial photo, 5·7 cm. 20° S. of W. of C.P.). The drain here was originally about seven feet deep and an auger hole sunk by the authors proved 6 ft. 3 ins. of peat and peaty sand. The surface of the ground here is calculated from the Drainage Board map to be about 56 feet above H.W.M. Mr. K. M. Harrisson obtained the bones from this site. A mutilated femur is now in the Tasmanian Museum, Hobart, while in the Queen Victoria Museum, Launceston, are three teeth (reg. no. 1763). A note by Mr. Scott in the Museum Register says that he re-excavated the site in September 1915, but found no further bones. Other nototherian remains in the Queen Victoria Museum are:

1. Two rami and tusks obtained from Mr. K. M. Harrisson in April 1924. See Scott and Lord 1925*b*.
2. Left cheek teeth and a coronoid process of a young *Nototherium*. Also other cheek teeth and tusks. Obtained from Mr. E. W. Reeman in 1924. See Scott and Lord 1925*b*.
3. " Two upper jaws and a box of various fragments " obtained from Mr. Burnley 14/3/49.

All the nototherian bones found in the Mowbray Swamp (apart from those in the mound springs) are various shades of brownish grey and grey, being stained presumably by the peat and probably such iron as is present being chemically reduced by the decomposing vegetable matter. That calcareous shells are preserved in excellent condition in some places, but dissolved by acids in others, shows a considerable range in pH conditions.

Articulated holotype skeleton of Nototherium tasmanicum. The articulated skeleton of *Nototherium mitchelli* obtained from Mowbray Swamp in 1920 and exhibited in the Tasmanian Museum, Hobart, has been figured, but not the more complete articulated skeleton in the Queen Victoria Museum, Launceston, which is the holotype of *Nototherium tasmanicum.* This is, therefore, now figured in Plates 1 and 2. The head is large, and remarkable for its strong nasal protuberance. *Diprotodon* has a similar protuberance, but not so strongly developed. The zygomatic arch is very strong and is sub-parallel to the main part of the cranium and not bowed. Like those in *Diprotodon* also are the curious scapulae and the rather flat humeri and femora. The tail is incomplete, but it can be seen that it was broad, flat, and rapidly tapering. The hind legs are markedly stronger than the forelegs and the pelvic girdle very powerful in build (cf. *Megatherium*). The animal apparently had the power of rising on its hind legs and this would increase the availability of food in the eucalypt forest of which the pollen analysis provides evidence. *Nototherium* was probably a browser rather than a grazer. Food would be plucked with the conical curved tusks and ground by the heavy molars. Such foot bones as are available show the animal was plantigrade. The feet are weak, as in *Diprotodon,* indicating a tendency for the foot bones to diminish and a pillar type leg to develop, as in the elephant. The skeleton of *Nototherium tasmanicum* and the other vertebrate fossils named in this paper need detailed study and taxonomic revision.

Palorchestes cf. *azael* was found by T. Edwards " in a drain in the Mowbray Swamp " and was acquired by Mr. H. H. Scott of the Queen Victoria Museum, who made this note; " Premaxillaries found by me, also zygoma, occiput, and scraps . . . During my visit to Smithton in 1915, I dug out the grave, with

Edwards, and found the nasals, incisor tooth, an occipital condyle, and other scraps." Scott (1916) described and figured a right upper maxillary with cheek teeth. He states that some nototherian teeth were also found by Mr. Edwards.

Phascolonus. The giant wombat is represented in Mowbray Swamp fauna by the shaft of a femur (reg. no. 1771) received by the Queen Victoria Museum on 8/10/12. It was represented by Hon. E. Mulcahy, M.L.C., and was found on " Wilson's Section ". The records in the Museum also mention part of a zygoma. In 1934 a leg bone of a giant wombat from Mowbray Swamp was received through Mr. T. Edwards.

Vombatus. In 1944 a small wombat jaw preserved in lithified cave earth was received by the Queen Victoria Museum through " Mr. T. E. Burns, from cave, Smithton." It is inferred that this fossil is not from the swamp area, but from the higher ground bordering the swamp to the east.

Large Kangaroos, &c. Mr. H. H. Scott registered as number 1766 in the Queen Victoria Museum, the shaft of a femur " regarded as being *Sthenurus* or *Procoptodon,* found at Mowbray Swamp, Smithton, by Mr. F. V. Brumby . . . in 1915 . . . The central muscular tract is very large, but the rest of the evidence is in favour of immaturity. This is a lusty growing animal minus the super-ossification of the adult." Another parcel contained " parts of three wallabies, toe of a large kangaroo and bones of a small rodent, all per Mr. T. Edwards of Mowbray Swamp (with emu bones) 14th. Oct., 1924. All found in a waterblow." This group of bones is medium reddish-brown and lightly mineralized. They are oxidized, whereas those from the peat are always chemically reduced.

" *Dromaius diemenensis* Le Souef ". In 1924 Mr. T. Edwards found a femur, two tarso-metatarsi, a cervical vertebra, and synsacrum of an emu in the Mowbray Swamp (reg. no. 1488). The preservation is similar to that of the *Nototherium* bones, viz. of dark colour, and with little if any mineralization. In crevices of the synsacrum some peaty material was noted containing fragments of freshwater shells. A fossil emu was discovered also during the draining operations at Irishtown in 1920 by Mr. E. H. Fenton (Scott 1924). The extinct Tasmanian emu was still in existence when white people arrived (Gunn 1853, Walker 1898, p. 22), but by 1832 it was extinct in the Derwent Valley (Backhouse 1843, pp. 30, 212). Scott (1932) recorded a fossil emu from Mole Creek in Northern Tasmania, west of Launceston. Near Mole Creek is Emu Plain, presumably named after those birds.

There are differences of opinion concerning what the taxonomic standing of the Tasmanian emu should be, i.e., whether it should constitute a species, a sub-species, or just a race. The R.A.O.U. Checklist (1926) makes the King Island emu a full species and the Tasmanian emus a variety of the mainland form. It might be anticipated that, if the emus on King Island between Victoria and Tasmania were isolated long enough to evolve a new species, the Tasmanian emus would likewise evolve and not remain a variety of the mainland species. Mathews (1910) provided interesting information on the Tasmanian emu and has more recently (1946) given its taxonomic standing as *Dromiceius novaehollandiae diemenensis* Le Souef.

On Mr. Shoobridge's farm at Mella (locality 7, Aerial photo 30,663, Smithton Run 7, about 9·2 cm. 6° W. of N. of C.P.) there is a somewhat circular patch

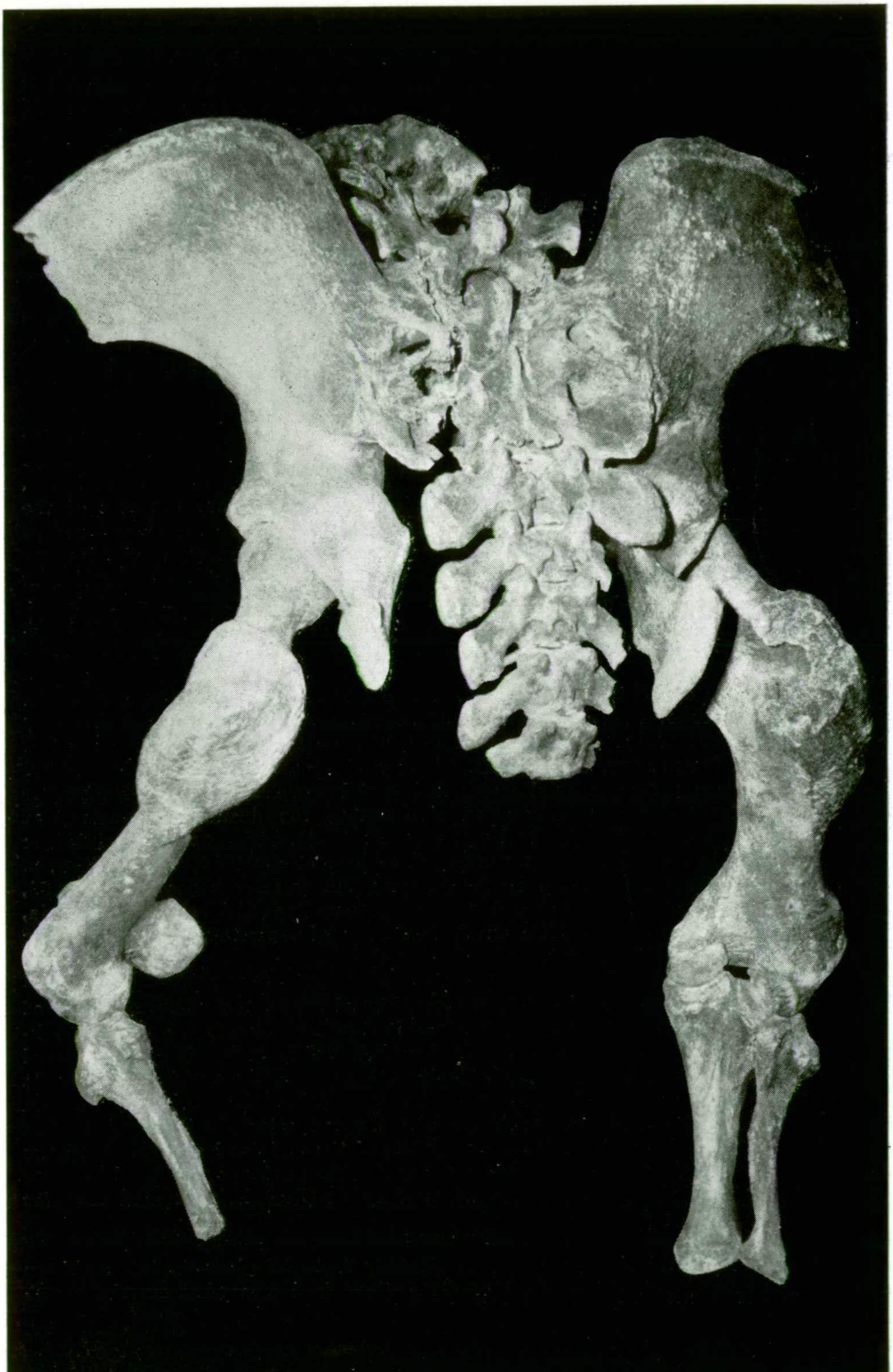


PLATE II.—Nototherium tasmanicum Scott. Holotype from Mowbray Swamp and now in the Queen Victoria Museum, Launceston. Hind view.

of marl not exceeding eight chains in diameter. A spade hole put down by the writers proved the following succession:

2 ft. peat
2 ft. marl (rich in mollusca and with some ostracoda)
2 ft. peat
White sand of unknown depth.

Hydrogen sulphide was detected during the excavation. From the marl Miss Hope Macpherson kindly determined for us the following mollusca:

Australpera tasmanica (T. Woods)
Austropyrgus nigra (Quoy and Gaimard)
Lenameria attenuata (Sowerby)
Melavitrina milligani (Pfeiffer)
Simlimnaea gunni (Tate).

Melavitrina is a carnivorous land snail, so was probably washed into the pond or small lake at Mella. The marl has been dated as older than 37,600 years.

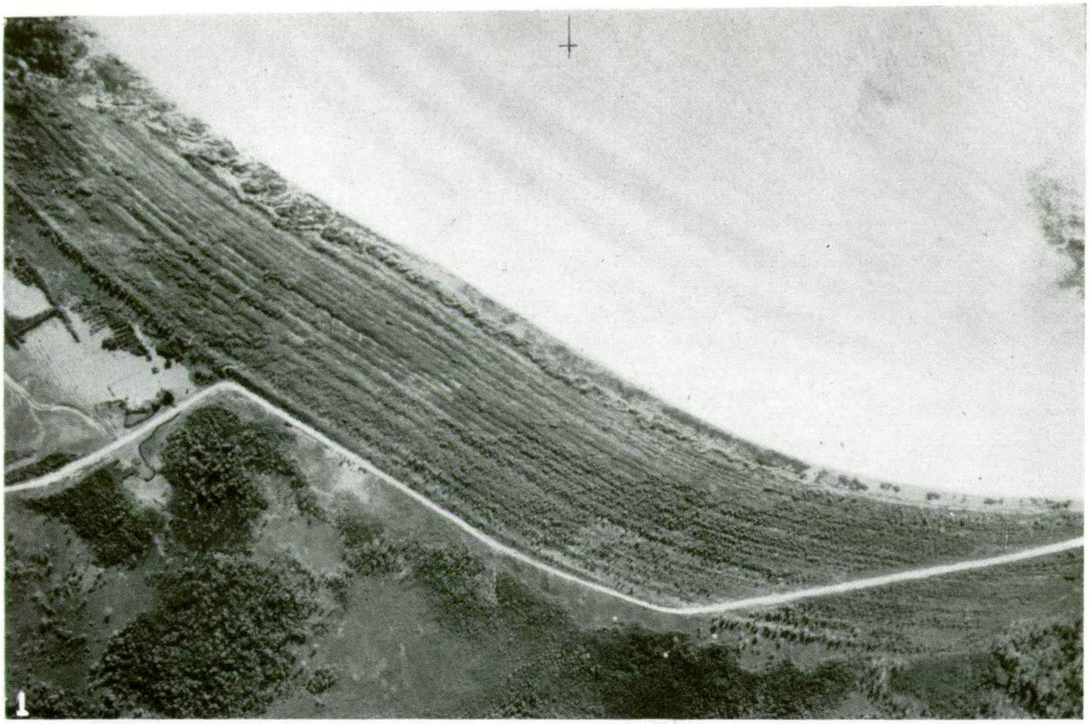
On the east side of the marl lenticle is an elongate patch of clay which seems to represent the bed of an incipient creek. The marl collected is similar to that of the Pulbeena Swamp, but no detailed work has been done on it yet. Analysis of a sample from Mella by Dr. A. W. Beasley gave:

Carbonates 92 per cent
Organic matter 3·3 per cent
Mineral matter 4·7 per cent.

The last-named consisted chiefly of well-rounded and sorted, very small grains of clear quartz, but some feldspar, muscovite, black iron ore, and other minerals were also present.

The same or similar ostracods to those found in Mowbray Swamp are found in the Tootgarook or Boneo Swamp in Victoria (Chapman 1919, Keble 1950, Gill 1953*d*) and in the Pyramid Valley Swamp in the South Island of New Zealand (Duff 1949, Hornibrook 1955, Deevey 1955). This distribution may well be due to birds. Cleland (1952) has shown how widely plants are distributed by birds in Australia and the same could well apply to ostracods. The Double Banded Dotterel (*Charadrius bicinctus* Jardine and Selby 1827) migrates between Australia and New Zealand (Stead 1932, Buddle 1951) and it may be responsible for the distribution of these arthropods. However, it is curious that the diatom florae as reported for New Zealand and S.E. Australia are not more alike.

Surface features in the Mowbray Swamp of considerable geological interest and pedological importance (see addendum on soils) are the spring mounds, or " blows " as they are called locally. These have been referred to by Noetling (1912*a*) and Nye, Finucane and Blake (1934), while Stephens (1913) has discussed the springs in the vicinity of Deep Creek. The sites of some of the mounds are shown in text-figure 5. They are usually between 10 and 20 feet high, with a low angle profile commonly between 5° and 10°. A typical well-developed mound spring is that on the farm of Mr. Ben Edwards at Mella (Aerial photo 30,663, Smithton run 7, 7·1 cm. 11° W. of N. of C.P.). Water used to issue from the top of the mound, causing swampy conditions round it, so a channel was cut in the north side to divert the water into a drain. The water is highly mineralized, issues at the rate of 600 gallons per minute (figure supplied by Mr. Edwards) and maintains a consistent temperature throughout the year of 66°F. Some of the water is utilized in a cowshed built on top of the mound (Plate 3, figure 2). The following section of the mound results from observations to a depth of 7 ft. 6 ins. in the channel draining the mound and this was continued down by auger to a depth of 11 ft. 3 ins. The beds have a low outward dip of approximately 3°.



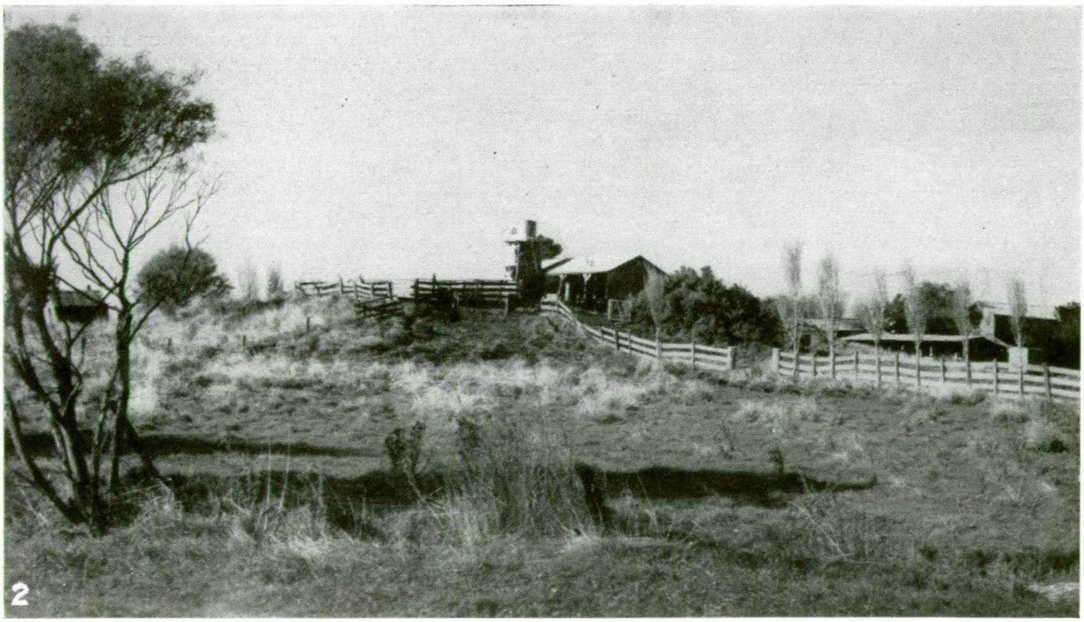


PLATE III.

FIG. 1.—Aerial photo of Holocene sand ridges near the Black River. The road is the Bass Highway. Published by permission of the Surveyor General, Hobart.

FIG. 2.—Mound spring on Edward's farm at Mella. Near the shed on the left is the section described on page 25.

Surface.	3 ft. 0 ins.	Light-brown soil and "travertine"
	6 ins.	Light-grey calcareous layer with shells
	1 in.	Black peat
	2 ins.	Calcareous layer as above
	6 ins.	Black peat
	9 ins.	Light-grey calcareous layer
	6 ins.	Black peat
	½ in.	Whitish shell layer
	9 ins.	Black peat
	½ in.	Whitish shell layer
	7 ins.	Black peat
	7 ins.	Shelly peat (bottom of channel)
	8 ins.	Black peat with wood
	8 ins.	Whitish to cream shell layer
	8 ins.	Light-grey marly sand
	6 ins.	Creamy calcareous layer
	6 ins.	Dark brownish grey marl with shells
	9 ins.	Light-grey marl of calcareous material and shells
	11 ft. 3 ins.	Total depth.

From our observations, and the reports of farmers, it would appear that alternations of peat and calcareous matter are typical of the Mowbray Swamp spring mounds. The shells are small snail shells such as have been recorded by Noetling (1912*a*) and Chapman (1914) from the marly layers of the Swamp. The marl is often rich in a calcareous alga. We were informed that from this and other mounds on the property, marsupial bones had been recovered. The property was formerly owned by Mr. Burnley and it is noted that Scott and Lord (1924) recorded a mutilated *Nototherium* femur from Mr. Burnley's farm on the Mowbray Swamp. The register at the Queen Victoria Museum records that on 14/3/39 two upper jaws of *Nototherium* and various fragments were obtained "from Mr. Burnley, Smithton". Dr. Cookson noted *Banksia* sp., cf. *Gunnera* sp., *Haloragis* sp., cf. *Hypolaena*, Compositae cf. Heliantheae, Chenopodiaceae and Gramineae pollens from a peat sample from the mound spring section on Mr. Ben Edward's farm at Mella. She did not find coniferous or fern pollens.

The age of Mowbray Swamp was given by Noetling (1914) and David and Browne (1950, p. 616) as Holocene. The present investigation shows that the Duck Bay Sand must have been deposited when the sea was about 70 feet higher than at present when the Rocky Cape Caves (see later) were being cut, or as it retreated. A sea-level at this height is elsewhere dated as Upper Pleistocene, so that this would be the maximum age for the Duck Bay Sand. The fossil shells found in the sand up to 50 feet above present sea-level are all living species and provide no accurate dating. However, all the sand ridges on the swamp antedate the present set which began to form when the sea-level retreated from a stand ten feet above that at present. Thus the Duck Bay Sand and Mowbray Swamp Peat are Upper Pleistocene, not Holocene. This conclusion is in keeping with radiocarbon datings received since the larger part of the paper was written, viz.—

Marl from 2 feet below surface, Shoobridge's farm, Mella (p. 25) > 37,760 years

Peat from 2 to 4 feet below surface, Lovell's farm, Mella (site of holotype of *Nototherium tasmanicum*) > 37,760 years.

These radiocarbon dates also indicate an Upper Pleistocene, not Holocene age.

Three lines of evidence combine to provide a picture of the conditions obtaining when the Mowbray Swamp was being formed:

1. It has already been noted that the peat was laid down chiefly in swales between ancient sand ridges and that the fossil vertebrates were generally found at the *base* of the peat. The evidence of the fossil vertebrates may therefore be taken to apply particularly to the earlier part of the period of peat formation. The fauna included herds of giants like *Nototherium*, *Palorchestes*, and *Phascolonus;* emus were also present. These mammals and birds could not possibly live in the jungle found on the Mowbray Swamp before it was cleared. We are informed by people who helped open up the district that no ground vertebrates were living there when white men came. The giant marsupials would need a good supply of vegetation for food but also space in which to move their huge bodies freely. Moreover, *Palorchestes* was a grassland type of kangaroo (Gregory, 1951, pl. 181) and would need at least an open forest type of environment. The same ecological argument applies to the emus.
2. Calcareous layers rich in freshwater molluscs, ostracods and algae occur as lenses in the peat. The evidence from these beds therefore applies particularly to the *middle* of the period of peat formation. These beds were packed with dense plant growth when in their natural condition just before clearing but at the time of their formation they must have been open sheets of water. For example, two feet thickness of 92 per cent calcium carbonate, free of peat, could not accumulate except under open water conditions. Some of the mollusca are lacustrine species. Ready access of light was necessary to grow algae and to provide the food for the ostracods and molluscs.
3. The palynological evidence is derived from peat about half way through the available thickness on Lovell's farm at Mella (loc. 2) and the peat of the mound spring deposit on Edward's farm at Mella (loc. 6) and so applies chiefly to the *middle and later* parts of the period of peat formation. In that the pollen grains are of Myrtaceae, *Banksia*, grasses, chenopods, composites and such like, an open forest association is indicated. Probably *Nototherium* browsed on the Myrtaceae chiefly, while *Palorchestes* grazed mainly on the grasses.

Thus, all three lines of evidence indicate a climate damp enough to cause peat formation, to form small lakes and to provide a flora rich enough to meet the needs of the herds of giant marsupials. On the other hand, it was dry enough to develop an open forest (not a wet forest) and so contrasts with the conditions prevailing at present. A period drier than the present in the Pleistocene of Tasmania would probably be an interglacial.

Scotchtown Cave

In order to provide limestone for the paper mills at Burnie, a quarry was opened in the Duck River Dolomite on the east side of the Scotchtown Road 3·2 miles south of Smithton. In 1942 a cave was revealed in this quarry with an average depth of two feet of chocolate-coloured cave earth. Bones at the surface were crumbly, but inside the cave earth numerous bones were well preserved. Mr. E. O. G. Scott made a collection of the bones and these are now in the Queen Victoria Museum at Launceston. These are creamy in colour and mineralized.

Scott reported finding giant kangaroos, bandicoots, small birds, *Nototherium tasmanicum*, *Thylacoleo carnifex*, *Tachyglossus*, *Vombatus*, the extinct Tasmanian emu and a reptile. Bones examined by one of us (E.D.G.) at the Queen Victoria Museum included:

Nototherium
Thylacoleo (the first record of this genus from Tasmania; see Gill, 1954*a*)
Palorchestes
Sthenurus
Macropus aff. *titan*
Wallaby
Vombatus
Sarcophilus (giant form; see Gill 1953*c*)
Thylacinus (large form but within the present size range; see Gill 1953*c*).

In the Queen Victoria Museum there is also a number of boxes of small bones, but there was not time to examine these. The Scotchtown Cave was probably a carnivore's lair.

Pulbeena Swamp

On the east side of Mowbray Swamp is a ridge of ?Cambrian bedrock. East of this ridge (which is half a mile to a mile across) is another swamp called the Pulbeena Swamp. Between Pulbeena Railway Station and the gantry at Fenton's Limestone Quarry on the east side of the railway line north-west of the station, there is a deep drain with floor 205 ft. above S.L. (Aerial Photo Smithton run 6, no. 30,686, 4·3 cm. W. of C.P.), shown on the map in Nye, Finucane and Blake (1934). The drain section reveals.

Surface of ground.	1 ft. 5 ins.	Yellow algal marl with peaty bands.	
	1 ft. 2 ins.	Black peat.	13,520 ± 540 years.
	4 ins.	Whitish marl with numerous shells.	
	10 ins.	Peaty marl.	
Floor of drain.	1 ft. 9 ins.	Whitish marl.	28,190 ± 1,520 years.
Auger hole.	6 ins.	Black peat.	
	2 ft. 0 ins.	Whitish marl.	

"Marl" is used in the sense of Pettijohn (1949). A smell of hydrogen sulphide emanated from the auger hole while it was being worked. On the surface of the spoil heaps consisting of material removed during the making of the drain, a shiny black jet-like substance was noted. Dr. J. A. Dulhunty has informed us that this is due to drying out on the surface and possibly also surface oxidation. "The irreversible changes from the soft-dull to the hard-bright conditions occur when absorbed water is removed from a colloid structure in which the micelles are just touching with contact points. The change is due to plastic deformation of the micelles on release of internal pressure of absorbed water. This produces contact areas instead of contact points between the micelles. The corresponding increase in the cohesive force is such that the micelles cannot be moved apart when water is reabsorbed on wetting. Thus the change is irreversible. If the peat has not reached the critical stage in colloidal development at which the micelles are just touching, then the change does not occur on drying." The same phenomenon was noted on the Mowbray Swamp.

Fenton's Quarry, north-west of Pulbeena Railway Station, reveals 3 to 8 feet of freshwater marl (Aerial photo Smithton run 6, no. 30,686, 4·8 cm. W.N.W. of C.P.). The following succession was determined:

Surface of ground.	1 ft. 0 ins.	Light grey marl with mostly minute shells. Algal remains present.
	8 ins.	Light yellow algal marl.
	2 ins.	Black peat. (?= peat near base of drain section).
Floor of quarry.	2 ft. 0 ins.	Light yellow algal marl to calcilutite, with freshwater gasteropods.
Auger hole.	3 ft. 3 ins.	Continuation of same bed.
	1 ft. 3 ins.	Dark grey peaty sand.
	1 ft. 0 ins.	Light yellowish grey quartz sand with calcareous material.
	6 ins.	Dark grey peaty sand.
	1 ft. 0 ins.	Chocolate brown peaty sand.
Total thickness	10 ft. 10 ins.	

The quarry is L-shaped, extending about four chains in each of the two directions. The beds exposed therein can be traced right round the quarry walls, although with some variation in thickness, e.g., the peat varies from 2 to 6 inches. There are some slight undulations which are probably due to differential compaction but otherwise the strata are horizontal. The amount of sediment from beyond the former lake waters was small, most of the material being of organic origin. The deposits indicate freshwater lacustrine conditions and imply a pluvial period. The vast tonnage of calcic materials in the Mowbray and Pulbeena swamplands has its origin in the underlying dolomite of the bedrock. The Mowbray Swamp deposits were laid down in swamps occupying swales, plus an occasional small lake. The peat is thus much more sandy than at Pulbeena. The Pulbeena Swamp deposits were laid down in a lake and as a result have a much higher percentage of calcic deposits, which are of both animal and plant origin. A detailed study of these deposits is now needed.

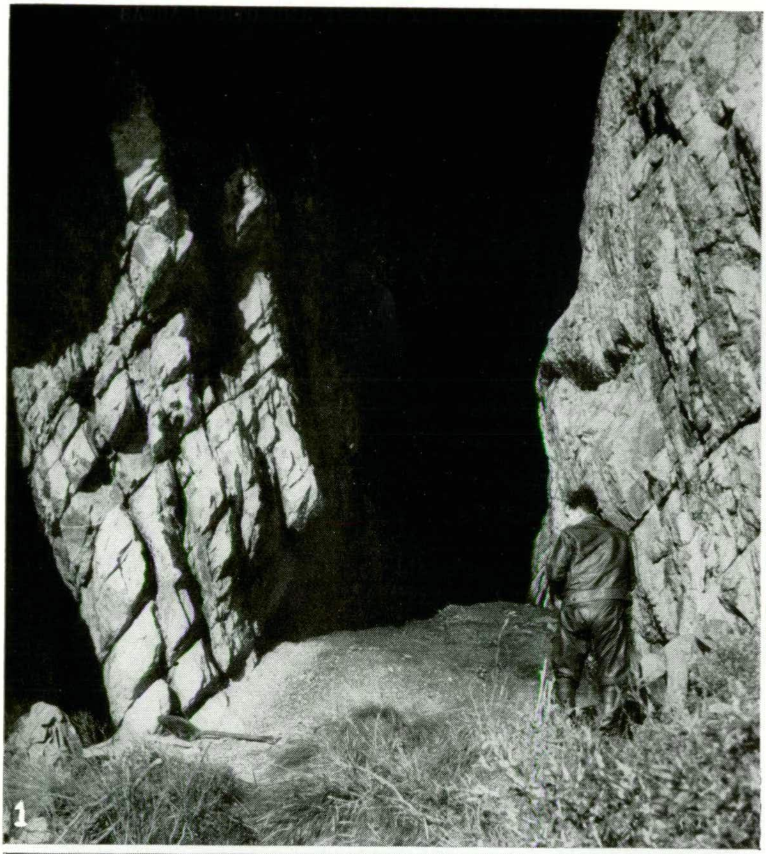
Being interested in the occurrence of *Limnicythere* in the moa swamp at Pyramid Valley in the South Island of New Zealand (Duff 1949), N. de B. Hornibrook of the N.Z. Geological Survey requested material for comparison. After restudying Chapman's types from Mowbray Swamp (Hornibrook 1953), samples obtained by us from Mowbray Swamp and Pulbeena Swamp were examined. The only sample providing ostracods satisfactory for his purpose was from Fenton's Quarry which yielded:

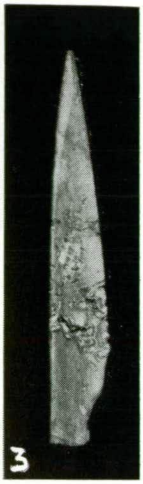
Candona lutea King
Ilyodromus stanleyanus (King)
Limnicythere mowbrayensis Chapman

See Hornibrook 1953, 1955.

Samples for radiocarbon analysis were taken from the north wall of the drain just east of the railway line and submitted to Dr. E. S. Deevey. Their C14 ages are:

Peat	2 ft to 2 ft. 7 ins. from surface	13,520 ± 540 years
Marl	5 ft. 6 ins. from surface	28,190 ± 1,520 years.





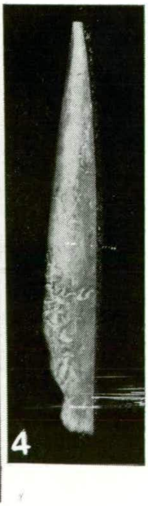


PLATE V.

FIG. 1.—Entrance to Northern Cave, Rocky Cape, 70 feet above ocean level. The floor of the cave is covered with aboriginal midden.

FIG. 2.—Fish bones from stratified layer of the Southern Cave, Rocky Cape.

FIG. 3.—Bone "awl" made from the fibula of a kangaroo. From fish bone layer, Southern Cave, Rocky Cape.

FIG. 4.—Reverse side of implement shown in fig. 3.

The first date is believed to be the true date, or near it, but the possibility of some contamination by the roots of plants living at the surface after the material concerned was laid down has always to be borne in mind. Such a C14 date is a minimum date. The Pulbeena peat date indicates an early Cary age (cf. Horberg 1955). The second date based on the marl may be affected by the shells and calcareous algae that form the deposit taking up "dead" carbonate from the underlying Precambrian dolomite. Deevey (1954) obtained spurious C14 dates of up to 2,000 years for plants living in a hard water lake. It is quite possible, therefore, that the given age of the marl is greater than that of the peat, partly because of greater antiquity and partly because of incorporation of non-radioactive carbonate from the bedrock. It is hoped later to make radiocarbon analyses of the whole series of alternating peats and marls of the Pulbeena Swamp deposits, thus making it possible to (*a*) compare and contrast the peat and marl calendars and (*b*) determine the rate of formation of the swamp deposits.

Comparison of C14 datings for the Mowbray and Pulbeena Swamps shows that the former is older than the latter. The Mowbray Swamp dates are older than the present range of radiocarbon. The Mowbray Swamp Peat was laid down in swales between sand ridges while the Pulbeena deposits were laid down in a lake. The former were laid down at a time less pluvial than the present, as is shown by the pollen analysis. The latter were laid down in a time as pluvial or wetter than the present. Some difference in age is therefore to be expected.

Rocky Cape Caves

On the east side of Rocky Cape (Aerial photo Smithton run 7, no. 30,627), there are two caves (Stephens 1908, Noetling 1912*b*, p. 103, Crowther 1925, Pulleine 1929, Edwards 1941*a*, Meston 1949), a more northerly one facing west, and a more southerly one facing east. In this paper they will be referred to as the Northern Cave and the Southern Cave respectively. They are cut from ? Precambrian quartzites of high dip (Plate 5, fig. 1), presumably by the sea. The two caves are at similar heights above the sea. A survey was made from the rocky floor at the entrance to the Northern Cave down to the sea, and the floor was found to be 75 feet above low water. Stearns (1935, p. 1939) and many others have provided evidence of a eustatic higher level of the sea of the order of 70 feet above the present level.

HOLOCENE SERIES (late Pleistocene at oldest)

Quarternary Deposits at Mount Cameron West

On the coast, both north and south of Mt. Cameron West, are ancient bays infilled with calcareous sand (Pl. 6, fig. 1) which rests on the Tertiary marine limestone and abuts against the basalt of the "mountain". Our visit was in winter after a storm, so that scour was at a maximum and screening by windblown sand at a minimum. Numerous aboriginal kitchen middens were noted in these sands. The dunes for one and a quarter miles south of Mount Cameron West were searched for the emerged marine shell beds of Quaternary age reported from there (Edwards 1941*a*) but only middens and redeposited midden shells (recognized by being of edible kinds and sizes with some burnt) were found. Shells had been washed from middens by rain and spring waters and redeposited so as to simulate stratified marine shell beds (cf. Gill 1951). It is, of course, possible that emerged marine shell beds occur in this area, but on the occasion of our visit the only beds seen by us of Quaternary age were those described above.

About a mile south of Mt. Cameron West, a section of the dunes exposed by erosion revealed three prominent soil horizons (Plate 6, fig. 2). An aboriginal midden was associated with the lowest, and therefore oldest, of the series of soils. This midden is considered to be historically ancient but geologically recent. The shells in the middens and redeposited beds were chiefly:

Dicathais textiliosa (Lamarck)
Haliotis ruber Leach
Patellanax squamifera (Reeve)
Scutus antipodes Montfort
Subninella undulata (Solander).

These are all molluscs that live on rocks, and so are quite out of character with this sandy environment. The aborigines probably collected them from the basaltic rocks round Mt. Cameron West, and took them to the shelter of the sand dunes to cook and eat them.

On the west side of Mt. Cameron West is a cobble beach which continues up as grassy slopes to a low vertical cliff whose base is of the order of ten feet above present sea-level. At the top of the low cliff is a well-developed terrace cut in the basalt and this is of the order of 25 feet above sea-level. There was not time to make accurate measurements and the tidal range is not known, but these two levels appear to be the work of eustatically higher sea-levels.

The Queen Victoria Museum at Launceston has a large piece of calcareous sandstone from two miles north of Mount Cameron West in which are preserved aboriginal carvings (Meston 1933, Nye 1941, Luckman 1951). Examination of the rock showed it to be an aeolianite (fossil dune rock). Mr. A. C. Collins kindly examined the foraminifera in a sample of this rock and found them to be of Quaternary age. They include *Lagena acuticosta ramulosa* Chapman and *Uvigerina bassensis* Parr, both typical recent Bass Strait forms.

Duck River and Duck Bay

The Duck River flows northward on the eastern margin of Mowbray Swamp, following the edge of the swamp deposits. It has incised its channel 15 to 20 feet. Duck Bay, into which it runs, is shallow with wide sand banks but with muddy sediments in places and rock outcrops on the floor of the bay. A survey chart and aerial photo mosaic kindly lent to us by the Smithton Harbour Trust show that the Duck River channel is only 3½ to 7 feet below M.L.W.S. at Smithton, but between Sampson Point and Perkins Bay the channel suddenly deepens from 8½ to 25 feet. Between Perkins Island and the point opposite, the depth of water reaches 31½ feet and this is on rock, presumably the Duck River Dolomite or perhaps basalt.

The low water datum in Smithton Harbour is the same as that of the Ulverstone tide-gauge, which is about a foot higher than the Devonport gauge. The spring tidal rise in the Harbour is about nine feet. The aerial photo mosaic shows that on Perkins Island and contiguous parts of the coast, the same series of recent sand ridges occurs as is described a little later from the vicinity of the Black River further east. It also shows that a delta, largely of sand (judging from its light colour) has been deposited where the Duck River debouches into Perkins Bay. Both the channel and the sediments are deflected somewhat to the east, as are those of the Black River and Detention River further east. This shows a "set" in Bass Strait towards the east in this area. The Australian Pilot (vol. 2, p. 7) states, "In the bight of the north of Tasmania . . . there is an almost constant current setting eastward during the greater part of the year."

PLATE VI.

FIG. 1.—View looking south from the summit of Mount Cameron West (basalt), showing Quaternary sands filling old embayment.

FIG. 2.—Natural section of a dune in the sandy area shown in fig. 1. Three soil layers can be recognized. An aboriginal midden is associated with the lowest layer.

Holocene Series of Sand Ridges

It is useful to distinguish between coastal *sand dunes* (generally 50 to 100 feet high and perpendicular to the direction of the prevailing winds by which they are built) and *sand ridges* (generally 10 to 20 feet high and following the coast whatever its direction) (Gill 1948, p. 10). The structures now discussed are sand ridges in this sense.

From the aerial photos available (none for the coast in the Smithton area had been taken at the time of the survey), it was noted that the series of sand ridges lining the present coast are well developed between the Bass Highway (which follows their landward margin) and the sea, three quarters of a mile to one and a half miles south-east of the Black River. A survey was made across the sand ridges at right angles to the beach, beginning a little west of the corner on the highway shown on aerial photo 30641, Smithton 7, 3·5 cm. N. of C.P. Behind the sand ridges is a flat swampy area with a small meandering creek which runs into a lagoon near the mouth of the Black River. Behind the swamp is what appears to be an old shoreline, approximately parallel to the present coast. The surveyed section is given in text figure 6 which shows a series of 18 ridges, all of which can be seen to be well developed longitudinally in the aerial photo (Plate 3, fig. 1). The ridges are protected by *Eucalyptus* trees and smaller plants. A good deal of burning off and land clearance has taken place and the sand is beginning to become mobile near the beach. The ridges are comparatively sharp and turn in to the mouth of the Black River. Their physiographic completeness suggests a recent geological age, as also does their relationship to the present coast and the existing river mouth. Only where there is a plentiful supply of sand are the ridges prominent, for they curve off and die out on approach to a rocky shore. In the area studied, their direction varies a good deal, but direction does not vary their character. They are known from other parts of the north coast of Tasmania. Similar well-developed series of recent sand ridges have been described from South Australia (Sprigg 1952) and New South Wales (Burges and Drover 1953).

Although, as one would expect, there is some variation from place to place, three phases of sand ridge building can be recognized in the area studied (see text-figure 6). Sand ridges are built at or near high water and the survey indicates that there has been a fall of sea-level of the order of ten feet. Teichert (1950), Fairbridge (1950) and Gill (1953*a*, 1955*a*) have found evidence in Australia (as others have overseas) of a retreat of the sea from a mid-Holocene level of the order of ten feet above the present. The authors quoted have found indications that this retreat took place in three stages, with stillstands at about five feet and two feet. To equate the three stages of sand ridge building with the three stages of marine retreat is, of course, unwarranted on the slender evidence available, but it may be advantageous to keep the possibility in mind. The ten foot sea level was associated with the postglacial thermal maximum (Gill 1955*a*), which was round about 5,000 years ago. Mehldahl (1950) refers to tidal forces in the sun's corona with a period of 308·52 years. If each sand ridge represents one of these cycles, then the sand ridge series represents 5,553 years. This is another intriguing parallel without any proved connection.

Ancient Series of Sand Ridges

Behind the Holocene series of sand ridges on Perkins Island is a more ancient series whose inland limit is shown in text-figure 4 by the line marked "apparent limit of dunes." They contrast with the recent ridges in that:

1. They are further inland and higher above present sea-level.
2. They are not sharp like the recent ridges, but depressed.
3. They are spaced further apart. Whereas the recent ridges average one for every 25 yards, the ancient ridges average one for every 80 to 100 yards.
   The recent ridges have a ratio of 1 : 3 or 4 with the ancient ridges in size and in frequency per unit distance.
4. There are more of them. Being less distinct, it is difficult to count them precisely, but about 40 can be made out or are suggested by the aerial photos.

Further inland again is a third area typified by the country around Mella, where sand ridges are not readily discerned either on the ground or from the aerial photos but are revealed by excavation or by the natural vegetation. The original vegetation reflected the difference between the sandy ridges and the peaty swales. Mr. F. S. R. Shoobridge of Mella advised us that the sand ridges were occupied chiefly by eucalypts with paperbarks, low tea-tree, a few blackwoods, clematis vines, and heath on the higher parts. The peaty areas were occupied by a dense forest of large paperbarks and blackwoods, a few eucalypts, and myrtle (*Nothofagus*) with low tea-tree and clematis. Mr. H. D. Ingle kindly examined pieces of wood collected by us from the peat of Mowbray Swamp at Mella and recognized them as roots of tea-tree, probably paperbark. They appear to represent the flora growing on the peat after its formation and not the flora forming the peat.

Middens in Rocky Cape Caves

Covering the floor of the Northern Cave and filling adjoining crevices is a copious deposit of charcoal, marine shells and the bones of marsupials, seals, and birds. The site is an aboriginal feasting place. It is said that the natives did not like dark caves, but they apparently appreciated the shelter of open caves such as those at Rocky Cape. Miss Hope Macpherson, Curator of Molluscs at the National Museum of Victoria, kindly determined the molluscs as follows:

Cellana rubraurantiaca (Blainville)
Dicathais textiliosa (Lamarck)
Fasciolaria australasia (Perry)
Floraconus anemone (Lamarck)
Haliotis ruber Leach
Mytilus planulatus Lamarck
Sabia conica Schumacher = *S. australis* (Quoy and Gaimard)
Scutus antipodes Montfort
Subninella undulata (Solander)

The marine shells are similar to those found in the Southern Cave but have a lower percentage of *Subninella* and a higher percentage of *Haliotis*. The bones include those of the Tasmanian Devil (*Sarcophilus*). Seal bones are numerous here but rare in the Southern Cave. As the Northern Cave is nearer the open sea, it is not surprising to find more *Haliotis* and seals in the midden remains.

The Southern Cave has an even greater thickness of midden material in it, determined by Meston (1949) as " just over fifteen feet deep ". The midden consists of charcoal, bones, and the following shells:

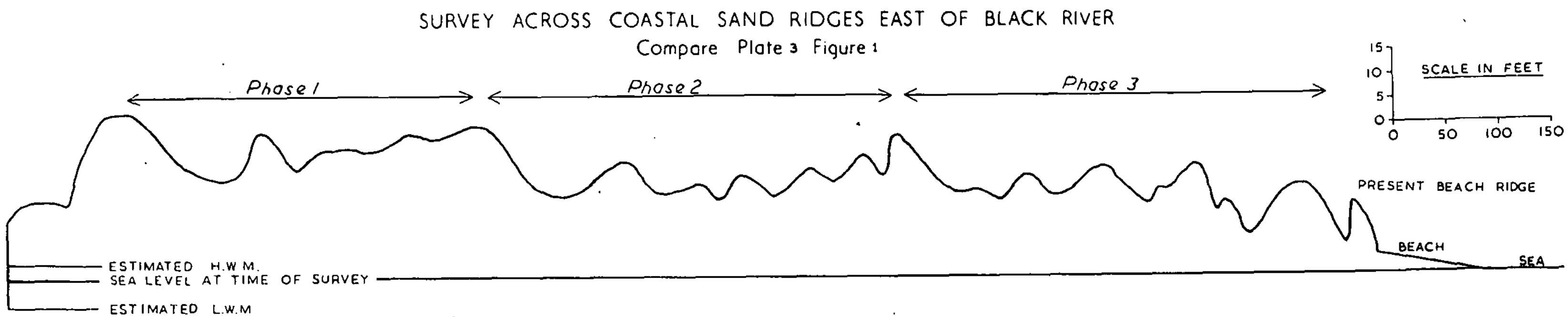

SURVEY ACROSS COASTAL SAND RIDGES EAST OF BLACK RIVER
Compare Plate 3 Figure 1
Phase 1
Phase 2
Phase 3
SCALE IN FEET
15
10
5
0
0
50
100
150
PRESENT BEACH RIDGE
BEACH
SEA
ESTIMATED H.W M.
SEA LEVEL AT TIME OF SURVEY
ESTIMATED L.W.M

FIG. 6.

MOLLUSCA

Austrocochlea adelaideae (Philippi)
A. camerata (Wood)
A. obtusa (Dillwyn)
Bembicium nanum (Lamarck)
Cellana rubraurantiaca (Blainville)
Cominella lineolata (Lamarck)
Dicathais textiliosa (Lamarck)
Fasciolaria australasia (Perry)
Haliotis ruber Leach
Mytilus planulatus Lamarck
Ostrea sinuata Lamarck.
Poneroplax constata (Blainville)
Sabia conica Schumacher = *S. australis* (Quoy and Gaimard)
Scutus antipodes Montfort
Siphonaria diemenensis Quoy and Gaimard
Subninella undulata (Solander)

BARNACLE

Tetraclita purpurascens (Wood)

The *Subninella, Cellana,* and *Haliotis* are the commonest but the *Dicathais* is also common, while *Scutus* and *Austrocochlea* are not uncommon. The deposit also includes bones of marsupials, birds and fish, numerous quartzite flakes and beach pebbles, which the aborigines probably used as hammer stones.

Fish bones in Midden

Where the midden deposits were undisturbed, some ten feet inside the cave, an excavation was made to a depth of three feet. From 18 inches to 2 feet, a layer was found richer in shells and bones and the latter included numerous bones of the parrot fish (kindly determined by Mr. Gilbert Whitley of the Australian Museum). See plate 5, figure 2. It has been claimed that no Tasmanian aborigines ate fish but this idea seems to rest chiefly on a statement by Captain Cook that the natives refused fish he offered them. West (1852) described an occasion when the Tasmanian aborigines "left their huts . . . in which were fragments of fish, baskets, and spears." Pulleine (1929, p. 147) found a parrot fish jaw at Rocky Cape; and he refers to "what appears to be representations of a fish" in aboriginal carvings (p. 149). Brough Smyth (1878, p. 392) said that the Tasmanian natives of the West Coast "speared sea fish in shallow water." Mr. Whitley said that if they were quick enough they could catch parrot fish by hand amongst the kelp, whence they would seek such molluscs as *Haliotis*. The plentiful fish bones from the Rocky Cape Cave indicate that some Tasmanian natives took fish there, presumably to eat. It could be that some tribes ate fish and some did not. Brough Smyth (1878, p. 393) said, "Certain kinds of food were prohibited, but under what regulations is not known . . . One set would not eat scaled fish." This suggests that some ate fish, while others did not. That natives refused fish offered to them by Captain Cook does not prove that even that group did not eat fish. They may have feared or suspected the strangers, or the fish may have been caught in deeper water and so be species unknown to the natives. That fish bones occur so seldom in Tasmanian coastal middens is also no argument that the Tasmanian natives did not eat fish. Victorian coastal aborigines ate sea fish, but in the hundreds of middens examined by one of us (E.D.G.), in only one were fish bones found, viz., the midden at Armstrong's Bay, Western Victoria (Gill 1951).

Bone Implement

The excavation in the Southern Cave at Rocky Cape also yielded a sharply pointed bone implement, like an awl, manufactured from the fibula of a kangaroo (Plate 5, figs. 3-4). The implement is reg. no. 48,237 in the National Museum of Victoria, and its measurements are as follows:

Greatest length as preserved	5·15 cm.
Greatest width	0·90 cm.
Greatest thickness	0·30 cm.

The markings on the point suggest that it was made by scraping and not by grinding as were so many Australian aboriginal bone implements. Noetling (1912*b*), working with T. Stephens at Rocky Cape, found spatulate ended pieces of fibulae in one of the caves (cf. Crowther 1925) but he did not believe they were implements. Lord (1926, p. 459) quoted as Captain Cook's account a statement that "one party of natives met with were armed with lances about two feet long, terminating with a shark's tooth or a piece of bone sharpened to a point." As this statement might have a bearing on the implement from Rocky Cape, we asked the Research Section of the Public Library of Victoria under the charge of Mr. P. Garrett to check this quotation. Miss P. Reynolds discovered that this quotation is not from Captain Cook's official log, but from Anderson's (1784) version "written in a more pleasing and elegant Stile". The official log (Admiralty 1784) referred to "a stick about two feet long and pointed at one end." The embellishment of the bone points appears to have been taken over from the account of the visit to Botany Bay in April-May 1770. So there is no evidence that sharpened bone points were used by the Tasmanian aborigines for tipping weapons. Other bone implements of this kind have been found in Tasmania, and the most likely explanation is that they were used as awls (Meston 1949, p. 149). The natives did not usually wear clothes, but "when sick covered themselves with a rug made of the skin of the opossum and of the kangaroo. The possum skins were laced together with sinews of the tail of the kangaroo." (Brough Smyth 1878, p. 399). Captain Cook's log (Admiralty 1784) also referred to females who "wore a kangaroo skin (in the same shape as it came from the animal) tied over the shoulders, and round the waist. But its only use seemed to be to support their children when carried on their backs." The manufacture of these items of clothing could be one use for bone awls.

In the Tasmanian Museum in Hobart, there are four Tasmanian aboriginal bone implements, one six inches long, and three eight inches long approximately. They all have spatulate ends. One of us (E.D.G.) found another pointed bone implement in a fissure deposit in limestone at Flowery Gully, north-west of Launceston. This implement is reg. no. 49,246 in the National Museum of Victoria, and its measurements are as follows:

Greatest length as preserved	4·4 cm.
Greatest width	1·35 cm.
Greatest thickness	0·55 cm.

Summary of observations on the Quaternary System

During the Pleistocene the Duck River cut a plains tract above the local base level formed by the rock bar at Perkins Island. Probably the plain was mostly cut in the soluble Duck River Dolomite, and was bounded to the west by low hills of Cambrian? argillite and greywacke, and to the east by steeper hills of dolomite and Cambrian spilite. When the sea rose to the 70-foot level, it flooded this plain and sand was deposited on its floor. As the sea retreated, sand ridges were left on the emerged coastal plain. During a period drier than the present, peat accumulated in the swales between the sand ridges and an open forest association constituted the flora. Giant marsupials inhabited the open glades. Possibly mound springs were already active, producing locally boggy conditions in which some of the animals were trapped. In places ponds and small lakes developed in which freshwater molluscs and ostracods thrived.

Later, in a time of higher rainfall, a lake at Pulbeena supported a rich growth of algae, molluscs and ostracods. In recent times (thought to be mid-Holocene), the sea stood about ten feet higher than at present, producing beaches and shore platforms now emerged. As the sea retreated, sand ridges were formed on Perkins Island, in the vicinity of the Black River, and elsewhere. Sometimes during the Upper Pleistocene or Holocene the Tasmanian aborigines arrived in Tasmania. Carvings and middens occur near Mt. Cameron West, and middens in the caves at Rocky Cape. Evidence occurs in the latter to show that at least some Tasmanian aborigines ate fish, and used bone as well as stone implements.

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ADDENDUM

THE SOILS OF MOWBRAY SWAMP AREA, TASMANIA

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The most important single factor in the genesis of the soils has been the influence of the alkaline spring waters (containing much soluble matter, particularly Ca and Mg) which have been ponded in the swamp and have irrigated the soils, enhancing their nutrient status and preventing the development of extreme acidity.

The main peat type—the granular peat as at Mella—was mapped as being more than 42 in. thick and was generally more than 6 ft. thick. This is a brownish black well-humified eutrophic peat with a deep horizon of brown well-decomposed peat of fine felty structure resting on sands below. A layer of calcareous peaty mud containing small mollusc shells often occurs (at varying depths) in the subsoil. Half a dozen transitional peat soils were recognized, one being a shallow peat over sand, another being a thin clay soil with peat subsoil underlain by sands, and a third a thin peat with peaty clay or clay subsoils.

Two series of fine-textured gley soils are associated with clay sediments—one series occupying shallow depressions occurring principally in the S.W., S. and N. central parts of the swamp while another series occupies a very gently sloping or shelving area along the northern half of its western boundary.

A third series of sandy gleys comprises the dominant soils of the swamp area. The organic-cemented sand "pan" beneath part of these (and some other) soils I interpret as a fossil soil horizon. This may be the B horizon of ground water podzols formed on the sandy plain, following emergence, under conditions of low water-table before the commencement of spring activity, or, more likely, before the influence of the spring waters spread as far as they finally did.

Heath plains composed of sands occur along the margins of the swamp to the north, east and south, and at the same general level as the adjacent swamp soils.

The soils of these plains are:

1. Ground water podzols—a better-drained type on the small sand banks and ridges, and poorly drained, leading to peaty, types on the wetter level to undulating areas.
2. Button grass peats—in depressions.

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CAINOZOIC

By EDMUND D. GILL

ADELAIDE
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VII

CAINOZOIC

By EDMUND D. GILL

with contributions by MAXWELL R. BANKS, A. H. BLISSETT, J. L. DAVIES, A. B. GULLINE, A. SPRY AND R. W. T. WILKINS.

MARINE SUCCESSION (M. R. BANKS)

Tertiary marine sediments occur as a discontinuous coastal fringe around the north-western part of Tasmania from Granville Harbour to Wynyard, on King Island, and in the Furneaux Group (Fig. 37). Quaternary marine sediments occur in the Furneaux Group, and emerged beaches and shell beds are known from many coastal areas.

A small outcrop of limestone at Temma (Ward, 1911) contains fossils which may indicate a Balcombian age. In the Marrawah area Tertiary limestones outcrop in several places. The lowest of these is at sea-level at Mt. Cameron West four miles north of Marrawah, and is of Upper Oligocene age (Gill and Banks, 1956). *Trybliolepidina* occurs five miles south-east of Marrawah in a limestone from the Welcome River, and closely resembles a species from Batesford, Victoria, suggesting correlation with faunal unit 9 of Carter (1959). The limestones near Green Point, one and a half miles west of Marrawah (loc. E. of Banks, 1957, p. 72) contain *Globigerinoides triloba* and may be correlated with part of the interval covered by faunal units 7-11 of Carter (1959, p. 49) all of which he considered Miocene. Limestones at Cape Grim are about 40 feet thick and contain *Planorbulinella, Cellepora gambierense, Aturia stansburiensis, Elphidium* and many other fossils. Pink limestone from the Montagu River, 12 miles west of Smithton, contains *Aturia australis.* A basaltic neck at Britton's Swamp 10 miles south-west of Smithton contains fragments of baked Tertiary limestone (Gill and Banks, 1956, p. 6).

In the Wynyard district, sandstone and sandy limestone about 80 feet thick constitute the Table Cape Group, which rests unconformably on Permian rocks at Fossil Bluff and disconformably on basalt near Doctors Rocks, four miles

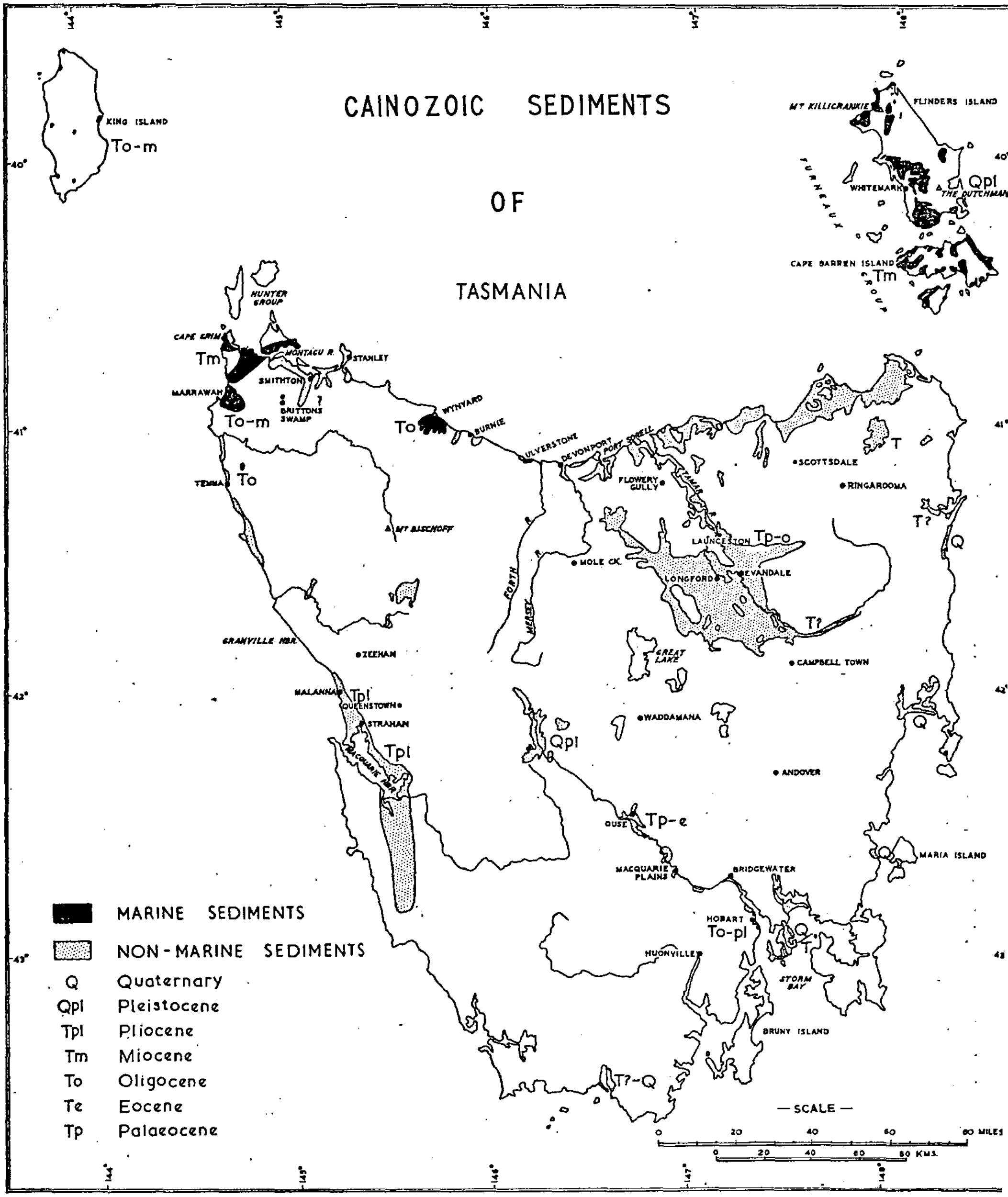

Fig. 37. Distribution of the Cainozoic sediments (Banks).

south-west of Wynyard. The basal formation, the Freestone Cove Sandstone, is up to four feet thick. It is a coarse ferruginous sandstone with pebbles and granules of quartz, Permian rock fragments and rolled and broken fossils. Over 300 species have been identified, including calcareous algae, wood, many invertebrates (especially gastropods and pelecypods), and sharks' teeth. Lithology and fossils indicate very shallow water deposition (Tate and Dennant, 1896). *Sherbornina atkinsoni* and many other fossils indicate correlation with the Jan Juc Formation of Victoria (Wade and Carter, 1957, pp. 157-158; Carter, 1959, p. 49), and some part of Carter's faunal units 4-6 of Oligocene age. At Fossil Bluff the Freestone Cove Sandstone grades up into the Fossil Bluff Sandstone which is almost 80 ft. thick and consists of fine- to medium-grained, calcareous, glauconitic, quartz sandstone and sandy limestone. Abundant fossils include plant remains, *Cellepora* spp., *Turritella* spp., *Aturia australis, Lovenia woodsi, Wynyardia bassiana* (the oldest known Australian marsupial), and a whale, *Prosqualodon davidi.* It is at least partly Upper Oligocene (Glaessner, 1955). Permian tillite is unconformably overlain by a conglomerate about 25 ft. thick containing basalt boulders at Doctors Rock. The conglomerate is conformably overlain in a structural basin by a basalt flow 50 feet thick, this by a few feet of Fossil Bluff Formation, and the last by basalt.

A silicified Tertiary limestone containing polyzoa, pelecypods and gastropods has recently been found near Granville Harbour.

Tertiary limestones are widespread on King Island (Banks, 1957) and are approximately equivalent to the Jan Juc Formation (Oligocene) of Victoria. Limestones and sands occur in the Furneaux Group. *Calcarina verriculata, Amphistegina lessonii* and *Planorbulinella plana* and other fossils indicating a Batesfordian age (Crespin, 1945, p. 13; faunal unit 9 of Carter, 1959), occur in a limestone from the township of Cape Barren Island.

Wilkins states: "On the eastern side of Flinders Island are two formations of probably post-Kalimnan, pre-Maretimo age. Kalimnan is Lower Pliocene and the Maretimo Member in Victoria is probably uppermost Pliocene. The formations contain similar suites of mollusca, and appear to be approximate lateral equivalents. A maximum thickness of three to four feet of white friable limestone (Dutchman Coquinoid Limestone) with numerous complete thick-shelled mollusca is exposed, about nine miles east of the Whitemark lime quarry at the foot of the Dutchman (type locality lat. 40°7'S., long. 148°10E'; see map Dimmock, 1957). The Cameron Inlet Marl is a green, glauconitic, shelly marl outcropping in the floor of the Nelson Lagoon drain. The two-foot section has been taken as the type locality (lat. 40°4'S., long. 148°11'E.). The Dutchman Conquinoid Limestone is difficult to trace across the eastern plain, but it appears to be the near-shore variant of the slightly deeper water Cameron Inlet Marl. The faunas of the two formations have a very strong Kalimnan aspect but when the Pliocene species is ancestral to a modern one, the Flinders Is. form is intermediate between the Kalimnan and living forms, e.g. *Bankivia, Bassina.*"

Marine transgression began at Table Cape, Marrawah, and probably elsewhere along the north-west coast in Oligocene time, and reached points now about 250 feet above sea-level. The sea withdrew after the Middle Miocene and no further marine sediments are known before those on the eastern side of Flinders Island (probably Upper Pliocene), which represent a transgression affecting the Furneaux Group or part of it.

NON-MARINE SUCCESSION (E. D. GILL)

Interpretation of the Cainozoic non-marine history of Australia has been greatly hampered by lack of adequate means of dating. Early workers had to depend for dating on extrapolation from marine rocks (a very limited opportunity), and on physiographic criteria. In the earlier part of this century, the classic work of Andrews (1910, 1914, 1934) on Eastern Australia envisaged a lateritized peneplain (dated as Miocene) broken up to tectonic movements (dated as late Pliocene to Pleistocene), but those datings were limited by the inadequate geochronology of the time. This standard interpretation was applied to Tasmania (Hills and Carey, 1949), but the development of Australian palynology now makes review practicable. As plant microfossils have been found in both marine and non-marine rocks, dependable extrapolation from marine rocks of known age is possible. It is now recognized that the geological history formerly telescoped into the Upper Cainozoic should be made to extend over the whole of that era.

Block-faulting produced grabens in which most of the stratified non-marine rocks of this era were deposited. Only a beginning has been made of the study of these, but it would appear that the Cainozoic history of Tasmania is similar to that of the rest of Eastern Australia, i.e. movements throughout the Cainozoic, but with maxima in the early Tertiary and the Pliocene-Pleistocene respectively, associated with extrusions of basalt called the Older Basalts and the Newer Basalts in Victoria (*cf.* Gill and Sharp, 1957). The initial datings for grabens in Tasmania are given below.

TAMAR GRABEN

(Johnston, 1875, 1888; Carey, 1947c)

Plants from a number of bores in the City of Launceston, and from an outcrop in Rose Rivulet near Evandale (Gill and Banks, 1956) are of Paleocene-Lower Eocene age ("Microflora B", Cookson, 1954a). The fossils found at Launceston include the zone form *Triorites edwardsii, Tricolpites gillii* (one of the earliest of the Australian angiosperm types), and the gymnosperm *Ephedra notensis* (Cookson, 1956, 1957). *Trisaccites micropterus, Microcachrydites antarcticus* and *Ephedra notensis* are known from Rose Rivulet. Animal fossils are rare in the graben; the freshwater mussels *Prohyria johnstoni* and *Alathyria tamarensis* have been noted (McMichael, 1957).

The sediments of the Tamar Graben consist of clays (highly carbonaceous in places), silts, greywackes and agglomerates totalling at least 900 ft. thick. A bore at Carr Villa, two miles south of Launceston, penetrated 570 ft. of sediments, and two bores at Belmont near Longford proved 690 ft. and 894 ft. (Johnston, 1888). The stratigraphy is very complicated. Current bedding on a large scale is common; cut and fill structures, evidences of subaqueous slumping, and palaeosols all occur. The Windmill Hill Greywacke (for stratigraphic terms see Smith, 1957), the Breadalbane Lignite and other formations make up the Launceston Group.

Landslips are common in these sediments with the result that many original sections are not now available. Specimens collected a long time ago, and lodged in the National Museum of Victoria and labelled "Evandale", quite likely came from the big cutting near Evandale Junction now covered by slip material. Their palynological analysis by Dr. Cookson reveals a flora younger than that in the Launceston bores, definitely post-Pebble Point Formation but probably pre-Yallourn. The graben filled over a period of time, and movements were intermittent, resulting in some alternations of greywackes and clays.

DERWENT GRABEN

Some hundreds of feet of clays (some carbonaceous), silts, greywackes and poorly sorted conglomerates and breccias occupy this graben (Johnston, 1880, 1882, 1885; Noetling, 1909; Lewis, 1946; Taylor, 1918; Banks, 1957). The flora has long attracted attention (Hooker, 1842; Darwin, 1844; Milligan, 1849; Mueller, 1874, 1883; Johnston, 1888; Arber, 1904; Gill, 1950b; Selling, 1950; Banks, 1955a). A log of silicified wood 40 feet long found near the Elwick Showground, Hobart, was determined by Mr. H. D. Ingle of C.S.I.R.O. Forest Products as *Eucalyptus* and confirmed by Pryor (1959). This is possibly the earliest indisputable record of *Eucalyptus* in Australia but Spry, later in this chapter, suggests that these sediments at Moonah and Cornelian Bay are post-basaltic and thus possibly as young as Pliocene or Pleistocene.

The ecology of such a graben is not favourable for the preservation of animal remains, but the Geilston Travertine (three miles north of Hobart) has preserved snails, an insect larva, and marsupial bones (Banks, 1957, and references). The travertine is probably a spring deposit, preserving remains as effectively as do the present mound springs of Mowbray Swamp four miles west of Smithton. Marsupial remains of apparent Tertiary age are also known from One Tree point, Sandy Bay, two miles south of Hobart (Johnston, 1882, 1888; Gill, 1957). The Geilston Travertine and other formations make up the Derwent Beds. The age of these sediments has long been a problem. On the basis of fossil fruits Johnston suggested the same age as the Launceston Group, but this is a facies rather than an age correlation. Palynological examination of carbonaceous deposits at Ouse (Cookson and Duigan, 1951; Cookson, 1953; Cookson and Pike, 1953) has revealed a flora including *Trisaccites micropterus* and *Microcachrydites antarcticus* which are early Tertiary forms found also at Rose Rivulet in the Tamar Graben. Jennings (1955) has described the Tertiary deposits of the Middle Derwent area near Ouse. During excavation for the University chemistry building at Sandy Bay, a ligneous clay was found containing a number of beech species, *Dacrydium mawsonii,* and ferns. Cookson stated the age to be post-Eocene and probably Yallournian. There is thus some evidence that the Derwent Beds range over a considerable period of time (as does the Launceston Group), but that in part the Derwent Beds are younger than the Launceston Group.

MACQUARIE HARBOUR GRABEN

Clays, lignites, silts, sands and conglomerates over 700 feet thick constitute the Macquarie Harbour Beds which outcrop chiefly on the north-east side of Macquarie Harbour (Johnston, 1888, 1890; Taylor, 1918; David, 1950; Bradley, 1954; Banks and Ahmad, 1959; Scott, 1960b). A section beside the road at the harbour edge just west of Strahan shows well-stratified deposits, rather unconsolidated compared with those of the Launceston Group and Derwent Beds. Previously interpreted as a glacial sequence (David, 1926, David, 1950, vol. 1, p. 625), they are now regarded as lacustrine. Two carbonaceous horizons with fossil leaves are present. That at about road level has abundant *Triorites harrisii, Nothofagus, Dacrydium* and *Acacia* (determinations by Dr. I. C. Cookson). *Acacia* is not known before the Pliocene, and Johnston recorded it from Tertiary beds at Malanna. Grasses and herbs are absent. In the carbonaceous horizon 50 feet above the road *T. harrisii* is not abundant, there is more *Dacrydium*, while *Acacia* is present with herbs and grasses. The lower level is regarded as Pliocene, and the higher level as Pliocene or Pleistocene. At least the upper part of the Macquarie Harbour Beds is late Cainozoic in age, and thus contrasts with the Launceston Group and Derwent Beds that belong to the early Tertiary. Seeds similar to the living *Banksia marginata* were found at Malanna (Banks and Ahmad, 1959). These authors consider the beds constituting the type "Malanna Glaciation" section of supposed Pleistocene age to be Tertiary graben deposits.

Scott (1960b) described the Macquarie Harbour beds as a series of unconsolidated sands and gravels, with bands of clay and lignite extending from Strahan and Malanna southwards to the Wanderer River. A minimum thickness of 730 feet exists, approximately 560 feet of which are below present sea-level. Cyclic sedimentation is common, as seen at Malanna and in the Conder River and Moore's Valley sections. Observations reflect unsettled conditions of deposition which may have been due to movement during deposition on the western boundary fault of the basin of accumulation immediately west of this locality. West of this fault the base of the Cainozoic succession can be seen resting on the Dundas Group several hundred feet above sea-level.

The Macquarie Harbour Beds are believed to have been deposited during the Upper Cainozoic in a graben. Movement on the boundary faults probably continued during sedimentation and the cyclic nature of the sedimentation could be related to this factor. Movement on these faults after deposition (post-Pliocene) is suggested by the presence of sediments 1000 to 1200 feet above sea-level.

Blissett states: "Quartz conglomerate and indurated sandstone occur (Waterhouse, 1914a, pp. 13-16) north-west of Zeehan. Extensive stretches of rounded gravels cap hills in Eureka Plains as far north as the edge of the Pieman Gorge, near St. Dyin Creek, and in isolated patches for at least two miles north of Donnelly's Lookout and east of Pine Creek. Rounded pebbles and cobbles of quartz tourmaline rock are found in all these localities. Montgomery (1894a, pp. 29, 30) regarded gravels at about 800 feet above sea-level north of the Pieman River as marine and formed on a plain of marine erosion, but Waterhouse regarded the gravels as fluviatile. Twidale (1957, pp. 12-13) considered the gravels north of the Pieman River to be marine or fluvioglacial."

SUB-BASALTIC DEPOSITS (E. D. GILL)

In addition to the graben deposits, there are extensive sediments preserved under basalt flows. The best example is in north-west Tasmania where an extensive basalt field occurs. Clays (some carbonaceous), silts, sands and gravels are found (Nye, 1924a; Nye and Blake, 1938; Gill and Banks, 1956). Selling (1950) records plants from under the basalt at Burnie.

POST-BASALTIC DEPOSITS (E. D. GILL)

Diatomites (Crespin, 1947a) have been recorded from the Inglewood Estate, Andover, and from Bishopsbourne, about seven miles west of Longford. Thirteen diatom species and sponge spicules have been recognized in the former, while the latter has yielded 26 species but without sponge spicules (det. B. Tindale). These are freshwater deposits of Upper Cainozoic age. River terraces and alluvial spreads constitute common Quaternary deposits throughout Tasmania.

Spry states: "Recent work on material from bore cores in the Derwent River for the Tasman Bridge suggests that Cainozoic sedimentation may have been more complicated than previously considered. The sediments at Cornelian Bay and Moonah are post-basaltic in age (Lewis, 1946; Yaxley, 1956) and occupy a channel to the west of the present course. The pre-basaltic sediments of Sandy Bay which were presumably deposited in the Early Tertiary graben are older, have a different flora and slightly different distribution. Evidence of a fault control of the location of the post-basaltic sediments is lacking."

VOLCANISM (M. R. BANKS)

Basaltic rocks are widespread in Tasmania (see Fig. 46). Confined lava fields are common in the north-west, in the Midlands, north-east and Derwent Valley, but extensive lava fields occur only along the north-west coast. Over 30 volcanic centres (Fig. 48) have been identified.

Interbasaltic sediments are known in a number of places and two inter-basaltic fossil forests occur (Banks, 1955; Anandalwar, 1960) in the Macquarie Plains-Glenora area.

Johnston (1888, p. 218) hinted at the existence of pre-basaltic streams, but the first map was that of Nye (1924a). The best treatment of the physiographic effects of the lavas is that of Edwards (1939). Since 1939 many people have dealt with the pre-basaltic topography (Prider, 1948; Voisey, 1949a; Fairbridge, 1949; Jennings, 1955; Spry, 1958b; McDougall, 1959a; Anandalwar, 1960), and presented maps of the pre-basaltic drainage. Spry (1958b, p. 120) was the first to show pre-basaltic contours. In most of the examples investigated, the pre-basaltic topography was rugged, with a relief of a few hundred to more than 1000 feet, with distances between the interfluves of up to five miles but in most places of the order of one to two miles. Some pre-basaltic streams

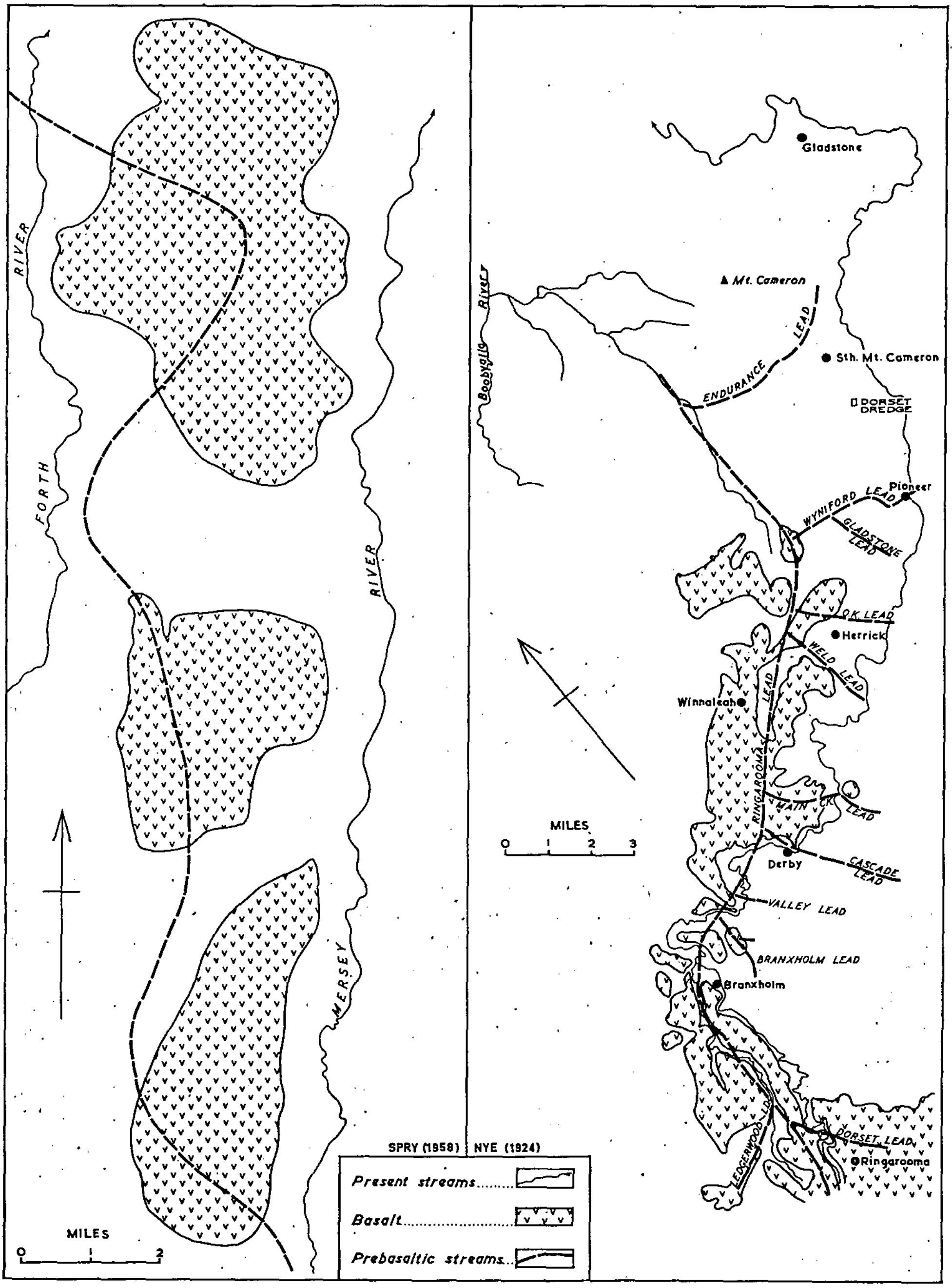

Fig. 38. Twinning and displacement of streams by Tertiary basalt (Banks after Nye and Spry).

with the effect on the drainage of the lava flows are shown (Fig. 38). The commonest effect of the basalt was to displace the stream laterally (e.g. Ringarooma), but twin streams were formed in some places (e.g. Upper Mersey and Forth resulted from the infilling of the stream bed beneath the present divide).

The dating of the basaltic rocks has long been a problem. An Upper Oligocene limestone disconformably overlies several hundred feet of pillow lava forming the north-eastern flank of an eroded volcanic cone at Cape Grim. A basaltic conglomerate and a flow underlie the Fossil Bluff Sandstone at Doctors Rock. Thus there is evidence of pre-Upper Oligocene or Lower Miocene volcanic activity at Cape Grim, Doctors Rock and possibly Marrawah. Palaeomagnetic work (Green and Irving, 1958, p. 11) indicates a Lower Tertiary age for The Nut at Stanley, and the lower flow at Doctors Rock. Basalt disconformably overlies Upper Oligocene limestone at Mt. Cameron West (Gill and Banks, 1956, p. 4). The Upper Oligocene limestone at Cape Grim is overlain by basalt. Basalt overlies the Fossil Bluff Sandstone at Wynyard and Doctors Rock. Basalt on Skittle Ball Plains near Great Lake is probably Upper Cainozoic on palaeomagnetic evidence (Green and Irving, 1958, p. 11). The upper limit on the age of the post-Upper Oligocene basalts is not clear. On physiographic grounds they are older than the sea-level of about 70 feet (Upper Pleistocene). Basalt near Wynyard and at Marrawah appears to form part of an erosional surface considered to be part of the Henty Surface which was deeply dissected before the Upper Pleistocene (Banks and Ahmad, 1959). Basalt near Port Sorell occupies a valley cut to 270 feet below sea-level in non-marine sediments of presumably Cainozoic age. Basalt in the Launceston area overlies sediments of Lower Oligocene or earlier age and is cut by an erosional surface, part of the Lower Coastal Surface (Davies, 1959a) which is pre-Upper Pleistocene. Basalt occupies a valley eroded in earlier Tertiary sediments, dolerite, Permian and Triassic strata to at least 156 feet below sea-level (Lewis, 1935, p. 80) at Hobart. Tasmanian basalts thus include some that are older than Upper Oligocene and others that are younger than Middle Miocene.

STRUCTURE (M. R. Banks)

Tensional stresses during the Cainozoic broke Tasmania into horsts and grabens (Fig. 39 and structural map). Four major grabens may be recognized—the Midlands Graben (Andrews, 1910, p. 428), the Derwent and Macquarie Harbour Grabens (Taylor, 1918), p. 176), and the Oyster Bay Graben (Banks, 1958a). The Midlands Graben bifurcates north of Campbell Town on either side of the Hummocky Hills Horst (Carey, 1947c). The western graben (Cressy Trough of Carey, 1947c, Port Sorell Graben of Banks, 1958a) extends as far as Port Sorell and Devonport. The eastern or Tamar Graben (Tamar Trough of Carey, 1947c) continues to the sea at the mouth of the Tamar River. The Derwent Graben contains the important Mt. Dromedary-Mt. Wellington Horst, within it. All four grabens show variations in trend along their length, and there is a vague convergence of the Derwent, Midlands and Oyster Bay Grabens towards Storm Bay. The relationship between the three eastern grabens

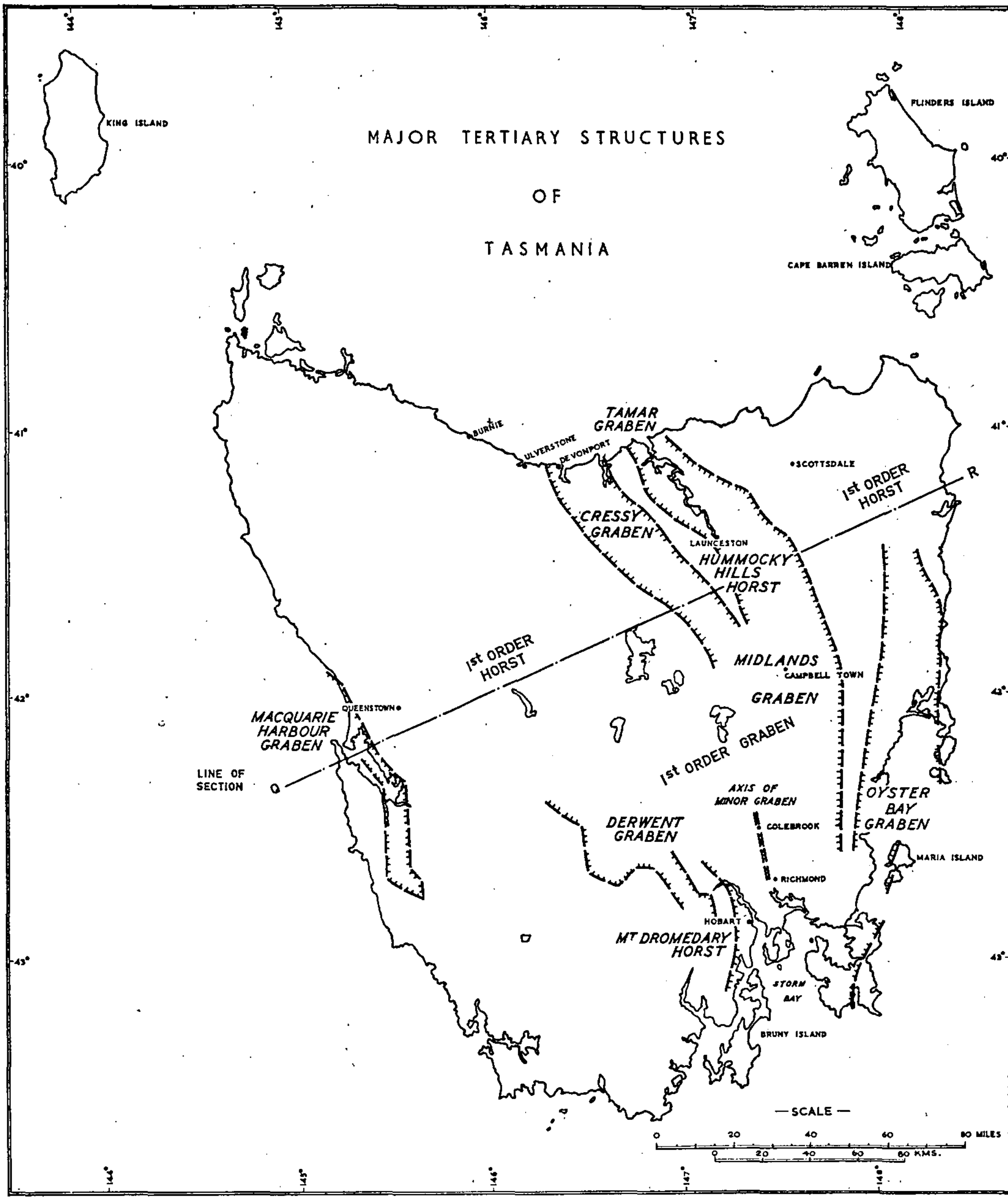

Fig. 39. Major Tertiary structures (Banks).

is not clear, but the trend of a deep but narrow graben between Richmond and Colebrook suggests that it may be the southerly expression of the Cressy Graben. Distinction is difficult between Cainozoic faults and those associated with dolerite intrusion in the Middle Jurassic (Banks, 1958a, pp. 236-7). Most of the Cainozoic faults dip steeply but some have dips as low as 45° (Banks and Ahmad, 1959, p. 125). The faults seem to be normal and most of them trend between north-west and north (Banks, 1958a, p. 245), but the detailed pattern is complex (see maps of McKellar, 1957; Blissett, 1959; Woolley, 1959; McDougall, 1959b; Anandalwar, 1960). Lewis (1927, p. 20) and Fairbridge (1949, p. 132) suggest some horizontal movement.

The age of the faulting is difficult to determine. Early Tertiary sediments in the Tamar Graben (e.g. at Trevallyn, near Launceston) were affected by later faulting. Near the University site at Sandy Bay, Hobart, beds of probable Yallournian age, deposited in the Derwent Graben, were later faulted (Johnston, 1888, pp. 281-2), and similar beds at Lower Sandy Bay have also been affected. Beds of Upper Cainozoic age in the Malanna area have been faulted and folded (Banks and Ahmad, 1959, pp. 125-6) and on physiographic grounds two late Cainozoic uplifts (or falls in sea-level) were postulated (*ibid.*, pp. 126-7). Banks (1957, p. 79) suggested late Cainozoic tectonic activity in the Furneaux Group, but on dubious grounds. Suggestions by Lewis (1927 and later) that there was post-basaltic faulting have been doubted (Hills and Carey, 1949, p. 37), but Carey (1960) has now advanced historical and topographic evidence for recent seismic activity in and near Tasmania. Present evidence indicates a period of faulting in late Mesozoic and/or early Tertiary time resulting in uplift of highlands and formation of grabens at or just above sea-level (Lewis, 1927) with some later faulting and uplift of upper Cainozoic age.

GEOMORPHOLOGY AND GLACIATION (J. L. DAVIES)

Perhaps the central problem in Tasmanian geomorphology at present is the question of the extent to which existing landforms are the direct result of tectonics or erosion. The older idea of a landscape stemming from Tertiary fault shattering of a widespread erosion surface(s) expressed in the writings of Lewis (principally 1945a) reached its fullest expression in the work of Carey (1947c) and the review of Hills and Carey (1949). More recently this hypothesis has met with difficulties, and the discovery that the relevant faulting is early Tertiary and/or late Cretaceous instead of mid-Tertiary has implied a relatively vast age for the numerous scarps implicit in the monocyclic view. An alternative hypothesis (Davies, 1959a) envisages a multicyclic landscape in which a series of stepped erosion surfaces has been produced by intermittent uplift. In this view the numerous scarps have been excavated along old trend lines and are not directly due to tectonic activity, although there may have been some minor rejuvenation. Davies recognizes five, and possibly six, major erosion surfaces, their stage of dissection depending not only upon age and position but also upon coincidence with resistant dolerite sheets and the sub-Permian plane of unconformity, both of which tend to impart an exceptional appearance of preservation. These are the *lower coastal surface* at about 300 to 900 feet, the *higher coastal surface* at about 1200 to 1500 feet, the *St. Clair surface* at about 2400 to 2700 feet, the *lower plateau surface* at about 3000 to 3500 feet and the *higher plateau surface* at about 3900 to 4400 feet. A possible additional surface at about 1800 to 2000 feet is less well developed or less well preserved.

Because of the general absence of definite time markers, the exact age of the postulated surfaces is very much a matter for conjecture at present. Davies tentatively suggested a Neogene age for all of them. That they are not of great age is suggested by the state of preservation of associated features and the apparent lack of warping. On the other hand, formation of the surfaces by intermittent uplift requires an overall emergence of 2000 to 2200 feet (sum of the differences between head and foot of adjoining surfaces) and there is no absolute reason why the oldest (*higher plateau*) surface should not be Cretaceous in age. The youngest (*lower coastal*) surface is later than early Miocene sediments which it truncates and earlier than late Pleistocene sediments which are superimposed. It is still only youthfully dissected in places and, around Longford, residuals are capped by lateritic ironstone. The multicyclic hypothesis of landscape evolution requires considerable further testing. It is clear that subaerial erosion has been guided by two notably different sets of structures in late Cainozoic times. In the centre and south-east of the island sub-horizontal dolerite and Permian and Triassic sediments are severely faulted. Drainage patterns are rectangular, reflecting the most important lines of faulting (and to some extent the joint alignment) in the dolerite. Residual landforms are apt to be tabular and plateau-like. In the west and north-east, where the folded Palaeozoic and Precambrian basement is uncovered, the rivers have evolved a trellis pattern with parallel ranges marking the strike of the harder rocks.

The dissection of the *lower coastal surface* must have been a Pleistocene event. Facets cut into the surface take the form of extensive terraces such as those supporting the Brickendon soils of Nicolls (1960) in the Longford area, and those making up the Firewood Siding Surface of Banks and Ahmad (1959) north of Strahan. Other lower terraces are probably related to either alternate wetter and drier phases in the Pleistocene or to eustatic changes of sea-level.

In south-eastern Tasmania in particular it is clear that many streams, both perennial and non-perennial, are underfit, being associated with valley troughs, terraces and alluvial deposits disproportionately large for the volume of water at present being carried. These streams do not rise in glaciated districts nor have most of them suffered recent capture. They may best be explained by supposing that they carried a significantly larger overall discharge during Pleistocene pluvial ages.

Evidence of periglacial and glacial conditions during the Pleistocene is well distributed in the highlands. Soils and landforms related to periglacial processes are found everywhere down to 2000 feet, though in places this limit is as low as 1500 feet. Characteristic features on the dolerite are yellow-brown solifluction soils (Loveday, 1955), block fields, block streams and residual stacks or tors (Davies, 1958). Jennings (1956) has reported rudimentary stone polygons which he believed to be active at about 3000 feet on the central plateau. The most conspicuous periglacial features still active are semi-perennial snow patches. Perennial snow is absent, but many patches lie for most of the year, and in some years all the year. Snow patch erosion occurs particularly above 3800 feet. In some favourable sites eroding patches may be found below this, but most active ones lie at elevations of 4500-5200 feet.

It has been found necessary to abandon the scheme of glaciations developed by Lewis (summary, 1945b). Jennings and Banks (1958) have presented the reasons for this, and have suggested that all the evidence available is referable to one glacial stage contemporary with the fourth in the northern hemisphere and much less extensive than Lewis envisaged in his "Malanna" ice sheet. The known stage appears not unexpectedly to have been a complex one with successive cirque, valley, glacier and ice cap phases in different districts, with evidence of ice retreat and readvance, and indications of ice moving in different directions in the same place at different times. But all known till and derived outwash and aeolian materials appear referable to one major episode of glaciation, and no stratigraphic sections have been found in which glacial deposits may be separated by significantly different degrees of weathering or by intercalated non-glacial horizons. Present data imply that either there has been only one major period of ice action in Tasmania, or more probably that the most recent glaciation has been the most severe, obliterating in large part the evidence of previous glacial stages. The regional account which follows is thus given in terms of one glaciation.

At its greatest extent, which probably was not everywhere synchronous, glacial ice was distributed in the form of one major ice cap, several smaller ice caps or plateau glaciers, a small number of cirque and valley glacier complexes, and a larger number of individual cirque glaciers (Fig. 40). The regional snowline, now lying between 5000 and 6000 feet, then lay between 3000 and 4000 feet, and there was probably a distinct east-west asymmetry on individual highland masses due to differential accumulation. In any event, cirques are markedly more numerous and lower on the eastern leeward side of the highlands, and glaciers originating on eastern sides moved farthest. A north-south asymmetry due to differential ablation is not surely discernible. Over the island as a whole, as distinct from individual highlands, the snow line rose from west to east with the general precipitation gradient. Thus, whereas cirque levels are low in the west and plateau glaciers formed at altitudes of about 3500 feet, in the east only the Ben Lomond plateau at about 4800 feet was glaciated, and the high plateaus of Mt. Barrow and Mt. Wellington lying at about 4000 feet did not develop glacial ice. Lying at a mean latitude of about 42°, and occupying an insular position it could be expected that Tasmanian glaciers displayed high rates of accumulation and ablation so that ice movement would have been rapid and the amount of work done relatively large for the time available.

The largest glacier, in its most extensive phase, was an ice cap about 40 miles in diameter, occupying the north-western section of the Central Plateau, the Du Cane Range and the Cradle Mountain Plateau. Outlet glaciers extended along the line of the Forth and Mersey Rivers (Spry, 1958b), into the Dove Valley at Cradle Mountain, into the headwater tributaries of the west-flowing

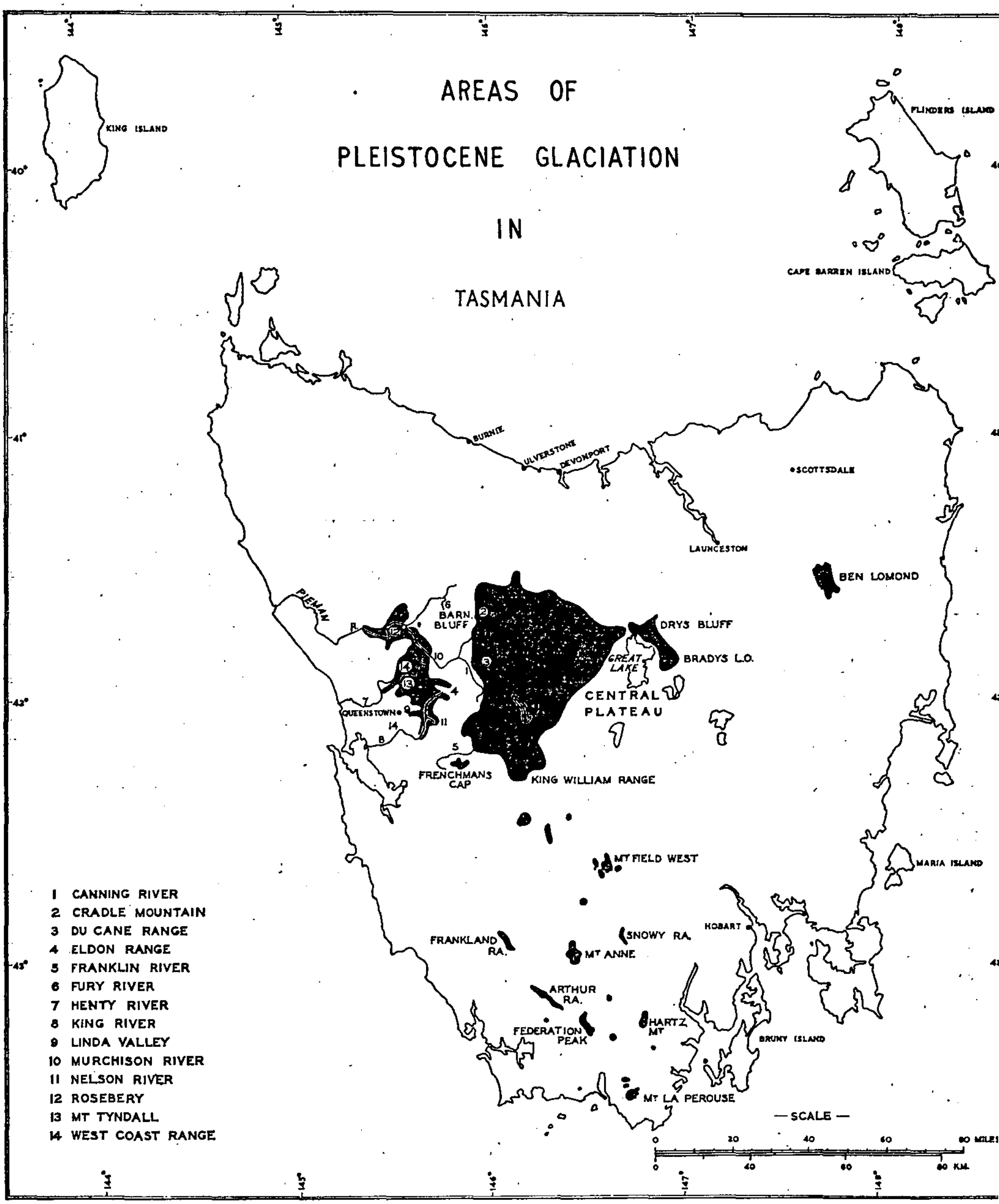

Fig. 40. Extent of Pleistocene glaciation (Banks).

Canning and Fury Rivers, and south-westward into the valley of the Franklin (Spry and Zimmerman, 1959). Eastward on the plateau, where the glacial morphology has been studied by Jennings and Ahmad (1957), a well-marked inner zone of predominant erosion is bounded by an outer zone of predominant deposition. This outer zone, averaging about six miles in width, extends from west of the Great Lake to the upper Derwent Valley and the foot of the King William Range, and forms the largest continuous expanse of till in Tasmania. The inner zone contains several thousand glacial lakes of varying size set in a field of *roches moutonnées* about 280 square miles in extent.

The second largest complex of glaciers was that centred on the West Coast Range and the Eldon Range, where precipitation today averages more than 100 inches a year. This complex consisted of three small plateau glaciers, one centred north of Mt. Tyndall, one south-east of the Tyndall Range, and a third on the north-eastern flank of the Eldon Range. These centres now display mammillated landscapes with numerous glacial lakes. From the small ice caps and associated cirque glaciers stemmed a number of outlet glaciers flowing north towards Rosebery and the Murchison Valley, west along the Henty Valley to the site of the present Zeehan-Queenstown road and south down the King River. The King River glacier was a particularly large one, fed from the Eldon Range and the plateau south-east of the Tyndall Range (Ahmad, Bartlett and Green, 1959). Expanding into the mouths of tributary valleys such as the Linda and Nelson, it caused interesting diversions of drainage and pro-glacial lakes. The varves at the head of the Linda Valley were the first of their kind recorded in Australia (Lewis, 1936) and fossil wood found within them has given a radiocarbon date of 26,480 ± 800 years B.P. (Gill, 1956).

Other plateau glaciers were located between Great Lake and Drys Bluff, between Great Lake and Bradys Lookout, and on Ben Lomond where several small more or less coalescent glaciers seem to have been involved, and on the King William Range, which in large part has a mammillated surface derived from a small ice cap adjacent to but distinct from the major Du Cane-Central Plateau sheet.

Elsewhere in Tasmania glacial ice was generated in cirques rather than on plateau surfaces, although sometimes (as on the Snowy Range) the cirque glaciers coalesced to form more extensive ice fields. The most spectacular of the cirque-cut massifs are those of the Frenchman's Cap, Mt. Anne, Mt. La Perouse, Federation Peak and the Frankland and Arthur Ranges, where horn peaks, aretes, glacial troughs and other features associated with the mature stage of the textbook cycle of alpine glacial erosion make up the landscape. The Mt. Field plateau, Hartz Mts. and Snowy Range are also extensively cirque-cut and many smaller groups of cirques or individual cirques occur on other ranges.

The Tasmanian coast is a conspicuously indented one formed by the post-glacial marine transgression into lowlands formed by sub-aerial erosion in Pleistocene low sea-level phases. The post-glacial sea appears to have reached a level about two to six feet higher than that of the present sea and this shoreline, called the Milford shoreline by Davies (1959b), can be traced around the island. The majority of the large constructional shoreline features were formed at the Milford level and have been modified since their small emergence by erosion and later addition.

In the coastal zone a conspicuous raised platform, often wide and continuous, seems to be the result of three old sea-levels at about 70, 50 and 20 feet above the present. J. N. Jennings (1959b) has presented reasons for believing that these levels may all be assigned to the last interglacial, and the resulting platform may therefore be the equivalent of similar features elsewhere to which the appellation "Monastirian" is usually given.

Evidence for Pleistocene subsidence off the east and south coasts includes:

1. The continental shelf is exceptionally narrow, and coastal outlines (emerged and submerged) suggest faulting.

2. Drainage divides are often notably close to the present shore, particularly on the drier east coast.

3. Lower erosion surfaces which slope gradually to the sea on the west and north coasts, are abruptly truncated on the east and south and are also much more highly dissected there.

4. The southern and eastern rias are deeper than the western and northern ones, suggesting that rivers which cut them were rejuvenated by subsidence of their low sea-level mouths.

CAINOZOIC HISTORY (E. D. Gill)

At the end of the Mesozoic, Tasmania was part of an eastern Australian land mass. The Australian area was of low relief and divided by a central sea that gradually retreated to leave widespread lacustrine and palustrine conditions. Marine, lagoonal and freshwater Cretaceous deposits occur in Victoria but no beds of this age have been recognized in Tasmania. The world-wide botanical revolution that brought in the angiosperms affected Australia as it did the rest of the globe. The fleeting and perhaps discontinuous connection between Asia and Australia (Teichert, 1958) that allowed the marsupials to enter, also admitted the angiosperms.

At the end of the Mesozoic or very beginning of the Tertiary there commenced the earth movements that have given Tasmania its particular shape and physiography. In nearby Victoria, warping and faulting were already well under way so that considerable sequences of Cretaceous beds were emplaced in basins. Faulting with less warping characterizes Tasmanian geology perhaps because of the highly competent dolerite sills. It may be significant that Bass Strait formed where the dolerite ceased.

In Paleocene-Eocene time, the sea was encroaching on the area now known as Bass Strait, as is shown by the marine rocks of this age in Victoria. In the King's Pier bore in Launceston a sample from between 52 feet and 78 feet produced a hystrichosphaerid, suggesting that the sea was not far away, even though no marine beds are found in the Tamar Graben. This fossil could have been blown in or carried on the foot of a bird.

Bass Strait appears to be a basin structure with land to the north and south and island chains to the east and west (J. N. Jennings, 1959a). It has been formed apparently by warping and faulting (as along the Otway coast). That the severance of Tasmania was complete by Oligocene time is suggested by the occurrence of marine rocks of that age from Marrawah to Wynyard in northern Tasmania, and in Victoria both in basin structures and on the Torquay dome. Even more widespread were the marine deposits of Miocene time, for they are found along both sides of the strait, and in a number of its islands. The Oligocene and Miocene marine sediments are transgressive, calcareous and often pauciterrigenous. The higher temperatures (Dorman and Gill, 1959) resulted in higher biological activity and so a high proportion of calcareous matter occurs in the sediments. No Lower Pliocene (Kalimnan) beds are known in Tasmania, but they occur in both east and west Victoria. In the Portland district there is a disconformity between the Miocene (Balcombian) and uppermost Pliocene (Maretimo Member) marine strata, whereas on Flinders Island a post-Kalimnan and pre-Maretimo deposit is present.

Eustatic oscillations of sea-level during the Quaternary caused Bass Strait to be alternately a landbridge and a seaway. Persisting evidences of these changes survive as submarine channels (J. N. Jennings, 1959a) on the one hand, and emerged terraces and shell beds on the other (Edwards, 1941b; Gill and Banks, 1956; Davies, 1959b). Among the latest evidences of change of level are the stumps of trees in peat amid the sand between tide levels near Badger Head, just west of the mouth of the Tamar River (Edwards, 1941b).

Tertiary marine rocks are absent from part of the west coast, from the south coast and the east coast. It may well be that they have been faulted or warped down. This explanation has been advanced for their absence from the east coast of Australia in general, and a recent bore on Wreck Island on the Great Barrier Reef supports this interpretation (Derrington *et al.*, 1960).

The thick beds of the Tertiary grabens indicate a complex history. There is much variation in ecology, as is shown by the changing composition of the flora and in the lithologies. Structures within the sediments (such as graded bedding) provide evidence of the nature of the environment, and dislocations, slickensides and other structures bear evidence of post-compaction slipping and faulting. Current bedding and cut-and-fill structures denote moving waters and clays rich in pollen (the lightest of sediments) are interpreted as indicating still waters.

The record of Tertiary animal life in Tasmania is as poor as that of the plant life is rich. The Fossil Bluff Sandstone, however, yielded Australia's oldest known marsupial, the possum *Wynyardia bassiana* (Gill, 1957). Although of Oligocene age, it is remarkably like the possums still living in the district, thus illustrating the primitive and conservative structure of this marsupial. The jaw of this animal is malformed, attesting an ancient disease. If Tasmania were isolated for the long period hypothecated (Oligocene to Pleistocene), it will be most interesting to see what effect this had on the Tertiary fauna of the island. In the Hobart district some fragmentary marsupial remains of possible Tertiary age are recorded, but the specimens were collected long ago, and cannot now be located for re-study. These and the Oligocene possum are our sum total of knowledge of the Tertiary non-marine fauna, except for a few snails and freshwater mussels.

However, there are some good Quaternary marsupial remains, such as those found in the Mowbray Swamp and nearby palustrine deposits. They include more or less complete skeletons of the giant herbivore *Nototherium*. The Scotchtown caves near Smithton, the Mole Creek caves, and the Flowery Gully fissure-deposits have yielded rich faunas. It is remarkable that no remains of giant marsupials have been found except in the north. The Midlands, for instance, appear to provide suitable habitats for giant herbivores.

CAINOZOIC CLIMATES

There is consistent evidence for higher temperature during a large part of the Tertiary in Tasmania. The Oligocene and Miocene marine beds in northern Tasmania contain organisms of tropical and subtropical aspect such as the foraminifera *Lepidocyclina* and *Carpentaria*, the echinoderms *Phyllacanthus*, *Schizaster*, *Eucidaris* and *Lovenia*, a number of corals, the lamellibranchs *Cucullaea*, *Hinnites* and *Spondylus*; the gastropods include numerous cowries and volutes, and shells of the *Columbaria*, *Murex* and *Astralium* groups (Gill, 1961).

Floral evidence for higher Tertiary temperatures is provided by the history of the Araucariaceae (Cookson and Duigan, 1951). The natural distribution of *Araucaria* at present is from the mountain forests of New Guinea (where the average temperature for the coldest month of the year is 64° F.) to the coastal rainforests of Queensland and northern New South Wales (54·2° F.). During the Tertiary, however, *Araucaria* flourished in Tasmania, and is well represented in southern Tasmania in the Derwent Graben.

The humidity of the Tertiary climate is shown by the much wider distribution of *Nothofagus*, the Southern Beech, which is at present limited to the high rainfall areas. This genus occurs in Tertiary sediments at the University site at Sandy Bay, Hobart, in the bore at Trevallyn powerhouse, Launceston, in the strata exposed in Rose Rivulet at Evandale, at Irishtown near Smithton, in the north-west of the State (Gill and Banks, 1956), at Strahan in the Macquarie Harbour Graben, and on King Island. Humidity is also indicated by the frequent occurrence in profusion of leaves of broad and thin structure, such as in the Tamar Graben (Carey, 1947c), Burnie, Mount Bischoff, the Macquarie Harbour Graben, and the Derwent Graben (Johnston, 1888). Further evidence is provided by the presence of ferns and fungi.

However, although humid climates have prevailed in Tasmania, there have been periods drier than the present, at least in certain areas. For example, in the Pleistocene there was a drier period in the Mowbray Swamp area, for instead of the jungle-like growth normal in that country at present, there was an open forest through which herds of the giant *Nototherium* roamed. Before clearing, the natural vegetation on Mowbray Swamp was so dense that no marsupial was known to have lived there. In the drier period of some 38,000 years ago (see Gill and Banks, 1956, for C14 dates) lakes were present, as shown by the beds of gastropods and ostracods. Plants of herbaceous type were common.

Windblown sand occurs as subfossil deposits of the Panshanger Association covered by recent flood-plain material in the Longford area (Nicolls, 1960, p. 5), as lunettes in the Longford area and further south (Stephens *et al.*, 1942; Nicolls, 1958), and as Upper Pleistocene and Holocene dune fields and beach ridges near Strahan and elsewhere along the west coast, in north-eastern Tasmania, and along the east coast (Davies, 1961).

Bauxite and laterite, being soils of deep leaching, require monsoonal conditions and their formation in Tasmania during the Tertiary (Owen, 1954) indicates periods of much higher mean temperatures with high rainfall.

The time of formation of the bauxites in Tasmania has been given as late Mesozoic (e.g. Hills and Carey, 1949). They are developed on dolerite of Middle Jurassic age and on Tertiary basalt as at Myalla, eight miles west of Wynyard, and Campbell Town. As similar climatic conditions probably obtained in Victoria at the same time, help in dating the period of bauxitization can be derived from examination of occurrences there. Bauxites are developed on Older Basalt (the oldest dated basalt is Eocene) and are overlain by brown coal of Yallournian (Oligocene) age in Gippsland. In the Melbourne area, the Nillumbik Peneplain is deeply kaolinized, but it is overlain by Older Basalt, in places itself kaolinized.

Conditions for deep leaching continued for a considerable part of the Tertiary, and bauxites and kaolinites may have developed at various times and in various places according to the groundwater conditions. In the bottom of the Tamar Graben, Paleocene-Eocene sediments rest directly on relatively unweathered dolerite, whereas on the upthrown side of the fault at Pleasant Hill large boulders of dolerite (i.e. eroded dolerite of the same sill as the graben floor) under Tertiary sediments have been altered, in places completely, to kaolinite (X-ray analysis by A. J. Gaskin). As the sediments are Paleocene-Eocene and erosion of the area was proceeding strongly in the Quaternary, this kaolinization took place in the Tertiary, altering both the sediments and the dolerite. Bauxite is recorded on dolerite from the same ridge, e.g. in Connaught Street and near The Gorge on the same wall of the graben. It has been inferred that the bauxitized dolerite extends under the Tertiary sediments at the bottom of the graben, but bores disprove this. Outcrops of dolerite beneath the basal sediments at Punchbowl and along the North Esk likewise reveal practically unaltered rock.

Some of the topmost beds of the Tamar Graben show signs of lateritization such as the formation of non-magnetic iron oxide layers and deep weathering (about 70 feet). This took place after the deposition of the sediments and before the strong dissection now in progress. A Lower Pliocene period of lateritization has been dated in Victoria but the lateritizing period in Tasmania is probably slightly older than in Victoria.

Dorman and Gill (1959) have carried out a series of palaeotemperature measurements by oxygen isotope analysis on fossils from marine Cainozoic beds in southern Victoria. The palaeotemperature curve is a measure of the changing mean temperature of the waters between Victoria and Tasmania and indicates

TABLE VI

Cainozoic sedimentary rocks of Tasmania.

AGE	MARINE	NON-MARINE
QUATERNARY	Flandrian and older fossiliferous muds and sands below present sea level and above it, in estuaries and along the coast. Emerged beaches consisting of sediments varying from sand to boulders.	Till and other glacial and periglacial deposits. Flights of fluviatile terraces. Lacustrine clays, silts, sands and diatomites. Macquarie Harbour Beds (in part). Cave and fissure deposits, often with bones. Palustrine peats and other sediments. Aeolianite including the "Helicidae sandstones" of Johnston. Coastal dunes, sand ridges, and associated deposits.
PLIOCENE	Dutchman Coquinoid Limestone } Cameron Inlet Group Cameron Inlet Marl } No known Lower Pliocene marine sediments.	Macquarie Harbour Beds (in part)—cobbles, pebbles, sand, silt, clay and lignite. High level gravels and conglomerates (in part).
MIOCENE	Limestones at Welcome River, near Green Point, Montagu River, Britton's Swamp and Furneaux Group Islands. Limestones at Granville Harbour and Temma.	High level gravels and conglomerates (in part).
OLIGOCENE	Fossil Bluff Formation } Table Cape Group Freestone Cove Sandstone } Limestones at Marrawah, Mt. Cameron West, Cape Grim and King Island.	Clays, sands and gravel of Derwent Graben (in part).
EOCENE—PALEOCENE	No known marine sediments.	Clays, sands and gravels of Derwent Graben (in part). Launceston Group of the Tamar Graben.

increasing temperatures from the lower to the middle Cainozoic, then a gradual decrease to the Pleistocene. This physical evidence checks with the biological evidence.

SYNTHESIS

Tasmania at the end of the Mesozoic was part of a vast eastern Australian island of low relief. In the Cretaceous? and early Tertiary, tectonic movements changed the eastern border of this land, fault block mountains were formed, and faulting modified coast and landscape. A near-central "rift valley" of almost meridional trend was formed — a vast senkungsfeld comparable with the east-west Great Valley of Victoria. The Tasmanian rift valley system was composed of grabens (such as those at Launceston and Hobart) in which thick non-marine sediments accumulated. Both these grabens had accumulated about 1000 feet of sediments by the Oligocene. The climate was warm and pluvial. The land was covered with a rich rainforest, below which deep leaching formed bauxites and kaolinites. The first record of marsupial life in Australia belongs to this time. Of the Miocene there is little record, except for the tropical marine beds in the north. Lack of record could mean lack of deposition and lack of tectonic movements.

The Pliocene and since belongs to the Kosciusko Epoch and the Macquarie Harbour Graben was formed at about this time. The palynological evidence suggests expansion of the grass family in those times. There was probably further sinking of Bass Strait, so that ancient river valleys protected by basalt were warped beneath the sea, and marine Pliocene sediments were deposited in the Flinders Island area. The amount of rapid erosion suggests that the highlands were further uplifted, and the present very rapid dissection of the Tamar Graben initiated. There is no evidence of the deep kaolinizing conditions of the earlier part of the Tertiary, but there was lateritization resulting from a warm climate with alternating wet and dry seasons. With the coming of the Quaternary, the modern eucalypt-acacia forests were fully established, and rainforest remained only in the very humid areas.

The Pleistocene was completely different from the Tertiary in climate, vegetation, land-sea relationships, fauna, and by reason of man's migration to Australia. Tasmania was a smaller island while the higher sea-levels of the interglacials persisted, and it joined with the mainland again during the low sea-levels, resultings in exchanges of plants and animals. Areas transgressed by the sea in north-west Tasmania became extensive peaty swamps when the sea retired, and calcareous waters modified the natural acidity of the peat to produce exceedingly rich lands. The luxuriant vegetation supported a rich bird and animal life, including the giant *Nototherium,* the "marsupial lion", giant kangaroos and wombats, and the small Tasmanian emu. In time of low sea-level, *Diprotodon,* the largest marsupial of all, crossed as far as King Island, but apparently did not reach Tasmania.

Last came the aborigines, an interesting race that become extinct before the end of last century.

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ℓecognition of the oldest known ossil marsupials from Australia

. PRELIMINARY study has been carried out on fossil remains inearthed in the British Museum) from a travertine deposit Tasmania. Regardless of the precise taxonomic assignments ltimately given to this material, the evidence we present that a iverse fauna of diprotodont marsupials existed in Australia in ite Oligocene time is of considerable importance. This evi-ence gives tangible support to the hypothesis that marsupials ave been residents of the Australian continent since the early 'ertiary at least. The basic differentiation of herbivorous)iprotodonta from Marsupicarnivora (Ride, 1964) very likely ook place before the separation of Australia from Antarctica. y late Oligocene time Tasmania was situated near 52°S ititude[1] bathed by warmer seas[2] and the travertine accumu-ited in an equable warm-temperate to subtropical environ-ient supporting a rich forest vegetation[3-5] the closest living quivalents of which occur in the uplands of New Guinea and lew Caledonia. Present-day representatives of some of the fossil iarsupials from the travertine still inhabit such tropical en-ironments in northern Australia and New Guinea.

Allport[6] has reported the discovery of fossil mammal re-iains in the travertine at Geilston Bay (42°50′S, 147°21′E) on ie northern shore of the Derwent across the estuary from 'obart, Tasmania. At that time the travertine outcrops at the ead of the Bay had been commercially quarried for over 0 years and were well known for their rich content of fossil lant and animal remains. Owen's report[7] that "fragments of ones, some teeth, and ungual phalanges of a small kind of *lypsiprymnus*, with probably also *Perameles* and *Phalangista*" ad been identified, led Allport[8] to state that the "bones all roved to belong to existing species", a conclusion that neces-tated a considerable revision of the geological history postu-ted for the site. Allport was forced to explain how the bones f living species could be found many feet below the ground ırface and beneath a basalt flow interbedded in travertine ssociated with a fossil flora having little in common with the resent-day flora of Tasmania. Nothing more was written bout the bones until Johnston[9] intimated that "it is to be feared ıey have not been preserved". The Geilston Bay collection ıd its whereabouts thus passed into obscurity primarily ecause of the belief that it represented only a Recent fauna.

Mahoney, conducting a search for bibliographic materials ılating to the Australian fossil mammals in the British Museum Natural History), located the Allport collection in the museum's oldings. Preliminary examination of the fragmentary remains aves no doubt that the fossils represent new taxa of marsu-als. An assemblage of Tertiary age is strongly indicated, and is recognition has led us to re-examine the geology of the eilston Travertine and associated basalts to determine the ze of the fossiliferous deposit.

The bones were found[6] in an "arenaceous clay, containing arse grit, and a few slightly rounded pebbles" interbedded ith the travertine. Matrix still adhering to some specimens ınfirms this description of the containing rocks. Allport also dicated that work west of the quarry towards the River erwent had exposed the east dipping contact of the travertine th the overlying basalt. Several geologists have observed e quarry working face, for travertine was produced from the e at least until 1924. Johnston[10] recorded (in descending der) the following composite section in the quarry and jacent area: 1.5 m of weathered basalt overlying 1.2 m of icified ostracod limestone, 1.8–2.4 m of yellow and brown ottled calcareous clay with marl lenses from which he alleged e marsupial remains were obtained, 3.1–3.6 m of travertine th plants and snails and 1.8 m or more of brown clay extend-ǵ below the level of the estuary. A similar section, but without the basalt, was recorded by Krause[11] in his map of part of the Hobart area and Nye[12] reported "thin layers of limestone occur above the basalt" as well as beneath. Moore[13] gives one of the last direct reports on the abandoned quarry and maps two outcrops of basalt along the south side of Geilston Bay, both of which are shown to extend to the edge of the estuary. Between these outcrops Moore's map shows "hornblende tuff", but this is a printing error, for the outcrops in that position are the Geilston Travertine (W. R. Moore, personal communication). Our observations show that the westernmost basalt outcrop overlaps Permian (Malbina) siltstone at a higher elevation than shown on Moore's map, and that it extended beyond the head of the bay to become continuous with the eastern outcrop, and to thus overlap the Geilston Travertine. These relationships seem to indicate that the basalt partially filled a narrow canyon containing a spring which had built up a considerable travertine apron before being buried by basalt and which subsequently continued to deposit travertine above the basalt. The combined observations of many geologists extending over 100 yr clearly indicates that the Geilston Travertine is mostly sub-basaltic (that containing the marsupial bones certainly so) and that travertine deposition was halted for a time by the basalt incursion and it is thus reasonably contemporaneous with the basalt. These conclusions had been anticipated[14].

It is now impossible (because of development) to secure a sample of the basalt at the travertine quarry. Therefore samples of the basalt from the western outcrop were collected for possible isotopic dating, and the least altered of these (Tasmanian Museum No. 22241; ANU No. 74-98) was measured by the K–Ar method. The sample was collected approximately 100 m from the head of Geilston Bay at sea level on the southern shore. This basalt contains about 5% mainly fresh olivine phenocrysts set in a well-crystallised fine-grained groundmass of plagioclase, clinopyroxene, olivine and iron oxide, together with 5% green mineraloid and minor calcite. The plagioclase shows evidence of some low temperature deuteric alteration. The basalt yielded an apparent age of 22.4 ± 0.5 Myr ($K = 0.765\%$; rad. $^{40}Ar = 3.07 \times 10^{-11}$ mol g^{-1}; 100 rad. ^{40}Ar/total $^{40}Ar = 90.0$; $\lambda_e = 0.585 \times 10^{-10}$ yr^{-1}; $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}; $^{40}K/K = 1.19 \times 10^{-2}$ atom %). Because of the somewhat altered nature of the basalt the measured age must be regarded as a minimum estimate for the time of crystallisation because of the possibility of some diffusive loss of radiogenic argon. The measured age approximates closely the estimated age of 22.5 Myr for the Oligocene–Miocene boundary[15], thus the Geilston Travertine underlying the basalt is considered to be late Oligocene or older.

The oldest previously known Australian marsupial *Wynyardia bassiana* was also from Tasmania at Fossil Bluff on the north-west coast where a skeleton was recovered from the Fossil Bluff Sandstone of early Longfordian age[16]. Recent radiometric calibration of the Longfordian Stage from the northern side of the Bass Basin in Victoria suggests that its base is approximately 21.4 Myr (ref. 17) and thus *Wynyardia* is of early Miocene age.

At least three mammalian taxa can be discerned among the very fragmentary remains from the Geilston Travertine. All identifiable remains seem referable to the Order Diprotodonta (Owen, 1866) and none can be relegated to the Peramelidae (Waterhouse, 1838) as Owen had stated. The largest form is represented by a fragment of a left maxillary with well worn dentition including part of M^1 and M^2–M^4 complete (BMNH 40157, length M^2–M^4 25.1 mm). This dentition resembles the Miocene palorchestine diprotodontid *Ngapakaldia* (Stirton, 1967) closely enough to encourage tentative assignment to that subfamily. It is about 60% of the size of *N. tedfordi* (Stirton, 1967) from the Ngapakaldi Fauna of the Lake Eyre Basin.

More abundantly represented is a second and smaller form that is postulated on the basis of tentatively associated edentulous jaw fragments, an unworn left M^1 (BMNH 32000, length 4.3 mm) and left M^2 or M^3 (BMNH 32001, length 4.2 mm), and other tooth and skeletal fragments. In mandibular dental formula and morphology these remains resemble those of the smaller species of *Phalanger* (Storr, 1780) and although other features bar assignment to that genus, reference to the Family Phalangeridae (Thomas, 1885) seems likely. A third form is indicated by a lower incisor which agrees best with those of living Burramyidae (Broom, 1898).

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PALORCHESTES AZAEL FROM PULBEENA SWAMP, NORTHWESTERN TASMANIA

by

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Abstract

Radiocarbon dating of wood contiguous with a mandible and incisor of *Palorchestes azael* Owen found in late Quaternary lake and swamp deposits at Pulbeena near Smithton shows that *Palorchestes* lived in the area sometime between about 50,000 and 65,000 years B.P.; during the early or early middle part of the Last Glacial Climatic Stage.

Introduction

A fossil mandible and an incisor of *Palorchestes azael* Owen were found together *in situ* at Pulbeena Limeworks (433732) 5km north of Irishtown and 4km south of Smithton (Fig.1). The Limeworks is located on part of Pulbeena Swamp; an extensive poorly drained area. The swamp is underlain by beds of freshwater algal and shell marl, and swamp peat deposits with timber fragments of late Quaternary age. These beds locally overlie quartz-rich sands and well-rounded quartz and quartzite gravels of up to 1 cm diameter which are probably also of Quaternary age. These surficial deposits rest on Precambrian Smithton Dolomite from which thermal groundwater springs bubble up through cylindrical conduits to the surface (Gulline, 1959). Water samples from two springs gave temperatures of 16.8°C and 17.4°C; total dissolved solid values of 750 and 800 ppm; hardness (expressed as $CaCO_3$) values of

670 and 720 ppm with Ca values of 105 and 115 ppm, and Mg values of 100 and 105 ppm (Tasmanian Department of Mines, Hobart).

[FIGURE 1]

The late Quaternary algal and shell marls, and swamp peats are mainly horizontally bedded but are locally deformed downwards in an inverted conical manner. The deformation appears to be due to collapse of the sediments over old spring pipes in the underlying dolomites. The marl and peat deposits indicate that the site has alternated between being a shallow lake fed by thermal groundwater and a swamp during the late Quaternary. The deposits vary in thickness from about 4m along the southern part of the north-south trending trench to at least 11m in test bores along a new east-west trending trench (Tasmanian Department of Mines, Hobart).

The fossil remains were located at 230cm depth in a steeply inclined (70-80°) dragline face on the eastern side of the north-south trending trench and 150m from the southern boundary of the field. The lower right mandible and incisor of *Palorchestes azael* were found in inverted position and contiguous with a piece of swamp wood which was sampled for ^{14}C dating. This giant marsupial perished either by becoming bogged while moving across the swamp peat surface or by drowning in the lake. The latter suggestion is preferred as it accounts better for the occurrence of one mandible and incisor entombed in inverted position, as floating carcases of large animals can easily become dismembered whereas the skeletons of bogged animals are frequently found intact. Despite careful searching no other bones were found.

Stratigraphy

The stratigraphy of the site was recorded from a well exposed section located 10m north of the fossil find into which the gently southward dipping bed containing the mandible and incisor was directly traced. The present stratigraphic investigation revealed a need for more detailed work at the site which is being undertaken by van de Geer. What follows is an interim assessment for the purpose of placing the fossil finds in a stratigraphic and palaeoenvironmental context. The stratigraphic profile is :-

0 - 12cm	black humic peaty soil; pollen sample 1
12 - 28	whitish-yellow algal marl with shells abundant between 24-28cm
28 - 36	dark brown to black peat with shells; pollen sample 2
36 - 44	whitish-yellow algal and shell marl
44 - 61	black humified swamp peat with sparse shells; pollen sample 3
61 - 68	whitish-yellow shell and algal marl
68 - 120	grey organic rich algal and shell marl; pollen sample 4
120 - 150	whitish-yellow shell marl
150 - 167	brown to black organic clay
167 - 176	yellow-brown algal and shell marl; pollen sample 5
176 - 183	brown organic clay with shells; pollen sample 6 from 180cm
183 - 188	yellow-brown algal and shell marl
188 - 219	dark brown organic clay with shells, plant roots and wood; pollen sample 7 from 192cm; equivalent of the bed containing mandible and incisor 10m to the south at 250cm depth; ^{14}C dated > 47,000 B.P.
219 - 278	yellow sandy shell marl with swamp grass (?) rootlets
278 - 284	greenish-brown sandy shell marl
284 - 298	brown organic shell marl with wood fragments; pollen sample 8
298 - 321	yellow-brown sandy shell and algal marl
321 - 325	greenish-grey shell and algal marl
325 - 340	brown organic clay with wood fragments; pollen sample 9
340 - 355	grey-brown organic clay
355 - 387	grey clay with quartz granules and small pebbles to 1cm diameter; also contains charcoal fragments and root structures; water table level

Palaeontology

Family Diprotodontidae

Sub-family Palorchestinae Tate, 1948

Genus *Palorchestes* Owen, 1873

Palorchestes azael Owen, 1874

The species is represented by two specimens, a lower right incisor (U.T.G.D. 94273) and most of the post-symphyseal part of a right mandible (U.T.G.D. 94271, 94272).

The incisor (figs. 2A-D) is spatulate, 62mm long, 25.5mm wide at the widest part (near the base of the crown) and the blade is gently arcuate forward and has a chord width of about 20.3mm. The crown is approximately 28mm long, the root about 34mm in length. The tooth is gently concave upwards (radius of curvature of dorsal surface approximately 110mm; that of ventral surface approximately 45mm). The tooth is thin in section, being only about 12.4mm thick. The incisor met the upper incisors along its anterior margin immediately posterior of which lies the broadly arcuate surface of wear, the lingual margin of which is sub-horizontal. As noted by Woods (1958, p. 180) the enamel is finely ridged and a low, sharp ridge extends posteriorly along the dorsal margin from the outer end of the surface of wear. The incisor is comparable in shape to that illustrated by Woods (1958, fig. 3) but is not as thick (12.4mm compared with about 20mm in his specimen) and somewhat more strongly curved in lateral view. The lower incisors of *P. parvus* De Vis have not been described but those of *P. painei* Woodburne appear to have similar dimensions but have not been figured.

The mandible (fig . 3 D, A-C) is incomplete, lacking most, if not all of the symphysis and the upper part of the ascending ramus. It is a right mandible. The maximum length is 243mm and the horizontal ramus is 51mm deep beneath $M_{\bar{3}}$. A short portion of the diastemal crest remains and descends at a moderate angle anteriorly from the premolar. The mental foramen is not preserved. The digastric process is very weak, the postero-ventral surface of the mandible descending on an almost circular arc (radius of curvature approximately 150mm) from the angular process to a position below $M_{\bar{2}}$. The post-digastric sulcus is scarcely excavate. The anterior margin of the ascending ramus rises steeply from just above the midline of the horizontal ramus to about the level of the top of the fourth molar before turning back at about 29^{o} towards the coronoid process which is missing. The masseteric fossa is broad and shallow with a low, broad ridge within it parallel to its posteroventral margin, delineated by a low, sharp post-masseteric eminence.

There is no masseteric foramen. The angular process is well developed, the posterior margin being almost perpendicular to the plane of occlusion of the molar teeth, and the dorsal surface almost parallel. Where the upper margin of the horizontal ramus close to the molar teeth is preserved, it is seen to have a narrow, rounded rim which is gently concave upward in longitudinal profile.

On the lingual surface of the mandible there is no sign of the symphysis. The digastric fossa is very shallow and opens posteriorly into a much deeper pterygoid fossa into which the mandibular foramen opens (the lip of the foramen has been broken away). The post-alveolar shelf is short and triangular and has a low post-alveolar process at its posterior termination. The pterygoid fossa extends back almost to the angular process which sweeps inwards almost at right angles to the plane of the mandible. The back margin of the mandible rises along a smooth elliptical curve towards the condyle.

In dorsal view the mandible is almost straight and the outer margin of the ascending ramus is at about 20° to the outer margin of the horizontal ramus. The premolar and molar teeth fall on a very gently sigmoidal curve which passes posteriorly and lingually from its anterior end, and at the posterior end the tooth row is almost parallel to the ascending ramus.

The premolar (15.5mm x 11.2mm) is small, somewhat ovate, and very unequally bilophodont with a crown 13.7mm high. There is a single high cuspid anterior to the centre of the tooth. The fore link is labial, short, steeply descending to the narrow anterior cingulum. The posterior link crosses the talonid basin slightly labially from the midline and expands dorsally onto the median part of the posterior cingulum. A short ridge descends lingually from the cuspid to close the talonid basin partly. There is a low, sharp process on the lingual side of the posterior cingulum. The tooth has two divergent roots, the posterior being the stronger.

The lower molars are subrectangular and slightly constricted at the ends of the median valleys. The teeth become both longer and wider from anterior to posterior as in *P. painei* (Woodburne 1967, p. 124). The dimensions are listed in Table 1 and compared with those in other specimens of *P. azael* and other species of *Palorchestes*. In molar dimensions the Tasmanian specimen clearly falls outside the ranges of species other than *P. azael*. The second, third and fourth molars are all narrower than any quoted by Woods (1958, p. 179) for the same teeth in *P. azael*, and the length to width ratio is higher for the fourth molar than any quoted by Woods. However, none of these differences taken singly or in combination are enough to warrant assignment of the Tasmanian material to a species other than *P. azael*. A noticeable feature of the figures quoted is the low range for length/width ratios of the teeth measured (in this respect the Tasmanian premolar is rather low). The range is 1.38 - 1.73, the 50 percentile being 1.50, the ratio which also approximates the mode using the method of running averages. The overall average ratio is 1.53. The low range and the shape suggest that the relative dimensions of the teeth are very stable and that the teeth are probably particularly well adapted for a grazing diet.

As the molars are closely similar to those described by Woods (1958, p. 181) no detailed description is warranted. Attention should, however, be drawn to the posteriorly developed median loop in the posterior margin of the hypolophid of the first molar. This loop, at the upper end of the hindlink does not occur on the other molars and does not seem to have been present in the specimens of *P. azael* studied by Woods, although Owen (1877, pl. CVI, figs. 2, 5) did figure it in specimens he identified as *P. azael* from fluvial deposits of a tributary of the Condamine River, Queensland. Woods did however figure this type of structure (1958, fig. 5, p.188) on the first and second molars of *P. parvus*. It is poorly, if at all developed in *P. painei* (Woodburne 1967, figs. 23, 24). The midlinks in the first and fourth molars are approximately in the midline of those teeth, but on the labial side of the midline in molars 2 and 3. This situation is somewhat similar to that illustrated by Woods (1958, fig. 5, p. 188) for *P. parvus* but different from that in *P. painei* (Woodburne 1967, p. 124).

Although there are some differences between the Tasmanian specimens and those described or figured earlier as *Palorchestes azael* the overall dimensions as well as tooth and ramus dimensions clearly establish this specimen as *P. azael*. In some minor aspects of the dentition there are similarities to *P. parvus* or to *P. painei*, as for example the position of the midlinks and the shape and size of the incisor. In lengths of premolar and first molar the Tasmanian specimens are intermediate between those of *P. parvus* and *P. azael* but closer to *P. parvus* in the first case and to *P. azael* in the second. The pattern of ridges on the occlusal surface of the premolar of the Tasmanian specimen shows more similarities to that of *P. azael* (Wood 1958, fig. 2, p. 181) than to that of other species. Thus the Tasmanian specimen may be regarded as *P. azael* but conservative with respect to premolar size and width of molars 2 to 4. As the teeth are in general about the same size and show about the same degree of wear as in other figured specimens of *P. azael*, the dental differences are unlikely to be the result of differences in ontogenetic age. On biological grounds it might then be suggested that this specimen is geologically at least as old as or may be older than the specimens from the Darling Downs studied by Woods.

TABLE 1

	Tasmanian	*painei* (1)	*parvus* (2)	*azael* (3)
P_3	15.5 x 11.2 [1.38] *13.7*	12.3 x 8.3 [1.48]	14.9 x 10.6 [1.41]	17.4 x 10.4 [1.67]
M_1	22.0 x 13.7 [1.61] *10.3*	(15.1-16.8) x (10.4-11.7) [1.44-1.5; av. 1.46]	19.7 x 12.3 [1.60]	(22.4-23.7) x (13.3-16.1) [1.41-1.68; av. 1.55]
M_2	24.0 x 15.6 [1.54] *13.0*	(17.4-18.3) x (11.5-12.5) [1.4-1.51; av. 1.47]	(19.1-20.8) x (11.1-13.7) [1.52-1.73; av. 1.62]	(22.4-28.5) x (15.9-18.1) [1.41-1.61; av. 1.54]
M_3	24.6 x 16.0 [1.54] *14.9*	(17.8-19.7) x (12.5-12.9) [1.39-1.53; av. 1.45]	(19.4-21.1) x (12.1-14.6) [1.44-1.71; av. 1.57]	(23.7-33.0) x (16.3-20.0) [1.45-1.66; av. 1.54]
M_4	25.1 x 15.3 [1.64] *14.0*	(18.8-19.6) x (12.8-13.7) [1.37-1.5; av. 1.46]	(19.1-22.0) x (12.2-13.9) [1.51-1.61; av. 1.57]	(24.1-29.5) x (16.2-16.5) [1.49-1.6; av. 1.55]

1. calculated from Woodburne (1967, table 23)
2. " " Woods (1958, p. 187)
3. " " Woods (1958, p. 179)

dimensions given as x x y [z] $\underline{c}$ where x = tooth length (anterior to posterior), y = tooth breadth, $z = x/y$, $\underline{c}$ = crown height

Environment

The shell marl was sampled from the horizon containing the fossils. The marl was rich in individuals of gastropods which were well preserved but was poor in species. These were identified by J.B. Smith (National Museum, Victoria) as

Endodontidae	*Trocholaoma spiceri*
Hydrobiidae	*Potomopyrgus* sp.
Planorbidae	*Gyraulus* sp. cf. *australis*
Planorbidae	*Physastra* sp.
Succineidae	*Austrosuccinea australis*
Sphaeridae	*Sphaerium tasmanicum*

A. Richardson (Zoology Department, University of Tasmania; pers. comm.) considers that *Austrosuccinea* suggests marshy conditions, while *Sphaerium* indicates the presence of still or very slow flowing water. The other species are consistent with the interpretation of the presence of a relatively shallow lake, as shown by the sediments.

Pollen samples taken from horizons 1-9, as indicated in the stratigraphy, were analysed to obtain data on possible vegetation/climatic changes that may have occurred in the region during the deposition of the lake and swamp sediments, and to aid in interpreting the environment which this *azael* inhabited.

The groups of pollen represented in horizons 1 to 9 are shown in Table 2 as percentage counts based on a sum of at least 300 grains of all pollen types plus trilete spores of *Dicksonia antarctica*.

TABLE 2

Sample	1	2	3	4	5	6	7	8	9
Depth cm.	0-12	28-36	44-61	95	167-176	180	192	284-298	325-340
throtaxis cupressoides						?	?		
onatia				?					
acrydium cf. *franklinii*							1.2		
othofagus cunninghamii						1.0	+	+	+
hyllocladus aspleniifolius						+	1.6		
ucalyptus	4.7	1.6	1.0	4.9	11.7	8.8	14.3	13.4	2.4
anksia				+		+		+	+
asuarina						+	+	+	+
ompositae	26.5	17.4	11.3	30.6	10.6	3.9	2.8	4.2	2.9
illeniaceae cf. *Hibbertia*				+					
pacridaceae cf. *Monotoca*					+	+	+	+	+
cf. *Sprengelia*								+	
eptospermum spp.	6.2	1.3			20.2	26.0	57.1	25.2	
elaleuca					1.4		1.2	2.1	
yrtaceae (others)	+	+	+		+	1.0	+	2.1	
apilionateae			+	+					
hamnaceae	+	+						+	
utaceae					+	+		+	
aryophyllaceae		+	+	1.0		+	+		2.4
henopodiaceae/Amaranthaceae	+	2.2	2.6	1.3	+	2.3	+	1.5	
yperaceae	2.8	6.0	8.4	2.9	6.2	13.0	5.9	35.3	84.0
oodeniaceae					+	+			
ramineae	52.3	65.0	70.9	49.8	39.2	10.1	4.0	3.3	1.6
aloragaceae				+					
lantago	+		+					+	
olygonaceae cf. *Rumex*	+						2.9		
ortulacaceae				+					
estionaceae	+	1.3	2.6	1.3	4.6	7.8	1.2	+	3.4
tackhousia monogyna	+				?			+	
mbelliferae	+	+	+	+	1.8	+	+	+	
iliaceae				?					
yriophyllum					+				
ymphaeceae		+					+		
otomogeton cf. *natans*		+	+	+	+	16.2	2.2	4.7	
riglochin									1.1
ypha								+	
yathea				?					
icksonia antarctica							+	1.5	
Jnknowns	*3.1*	*2.2*	*0.6*	*3.6*	*0.7*	*2.9*	*3.7*	*1.8*	*0.5*
Σ	321	317	309	307	436	308	322	337	380

+ < 1%

The only significant components of the pollen spectra include *Eucalyptus*, *Leptospermum*, Compositae, Cyperaceae and Gramineae. In horizon 9 local Cyperaceae is so dominant and the input of other types so low that no assessment of the regional vegetation is possible. In horizons 5 to 8 *Eucalyptus* and *Leptospermum* are important but decrease sharply between horizons 5 and 4, while Compositae and Gramineae markedly increase from horizons 6 to 4. Gramineae reaches a maximum of 71% on horizon 3,but declines again in the surface horizons. There was very little pollen in the surface horizon which contains introduced composites and has been cultivated.

Ratio curves (Fig. 4, curve 1) which show the combined regional tree pollen component *Eucalyptus* plus the local wet site small tree and shrub component *Leptospermum* against the probable regional Gramineae and local Cyperaceae non-tree pollen components, and (curve 2) the regional *Eucalyptus* against the regional Gramineae components, both follow the same trends through time. The ratio curves show that major regional changes in vegetation occurred during the deposition of the lake and swamp sediments and that the changes are separable from local site changes. The curves indicate an early stage when eucalypt woodland was present. This vegetation was gradually replaced by an open grass-composite (probably mainly shrubby species) vegetation which was further replaced by a grass dominated vegetation before a return to eucalypt savanna. The pollen evidence suggests that *P. azael* inhabited eucalypt woodland which the ^{14}C dates indicate occurred in this region during the early and middle part of the Last Glacial, and that the dominant vegetation was reduced to a shrub-composite and grass steppe during the maximum cold phase of the Last Glacial Stage.

Dating and Comparisons

A sample of timber contiguous with the mandible gave a ^{14}C age of > 47,000 years B.P. (GrN-7322) at the 3 σ level, but by using the 1 σ criterion the result is 54,200 $^{+11,000}_{-\ 4,500}$ years B.P. (W.G. Mook, Natuurkundig Laboratorium der Rijksuniversiteit, Groningen, Netherlands, pers. comm.). The assay indicates that *Palorchestes azael* lived in the area between about 50,000 and 65,000 radiocarbon years ago; during the early or early middle part of the Last Glacial Climatic Stage. In 1956 two ^{14}C assays were obtained by Gill and Banks on peat from between 62 and 80cm and on shell marl from 170cm depth in a section adjacent to Pulbeena Railway Siding. The final assays gave radiocarbon ages of 13,690 ± 550 years B.P. (Y 229-1) and 27,900 ± 2,000 years B.P. (Y 229-2) (Barendsen, et al., 1957). The three radiocarbon assays indicate that average sedimentation rates were between 4 and 6cm per 1,000 years over the long term, and that the 4 to 5m of sediment exposed at Pulbeena Swamp represents the lacustrine and swamp sedimentation of the entire Last Glacial and Holocene climatic stages (i.e. approx. 75,000 years).

Palorchestes cf. *azael* Owen fragments have been recorded from a drainage ditch excavated in peat deposits at Mella 6km southwest of Smithton (Scott, 1916). The peat deposits of this area overlie marine sands of probable Last Interglacial age and although they have yielded a ^{14}C age of > 37,760 years B.P. (Y 148-2) for a sample taken between 60 and 120cm depth (Gill and Banks, 1956), the date is unrelated to the *Palorchestes* finds except to indicate that the peat which contained them is mainly of Last Glacial age. Bone fragments of *Palorchestes* are included in the marsupial remains from Scotchtown Cave 5km south of Smithton found by E.O.G. Scott in 1942 and reported in Gill and Banks, 1956, but these deposits have not been dated. Recently, a lower right lateral incisor of *Palorchestes*, probably *azael*, has been obtained from bone deposits in Chamber A of a cave system 10km south-southwest of Montagu which have not yet been dated (P. Murray, Department of Anatomy, University of Tasmania, pers. comm.).

Although the evidence indicates an early to early middle Last Glacial age for the find of *P. azael* Owen at Pulbeena, this species may have lived in northwestern Tasmania during the greater part of the Last Glacial Climatic Stage.

Acknowledgements

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Figures

1. Location of Pulbeena Swamp.

2. Lower right incisor of *Palorchestes azael* Owen.
U.T.G.D. 94273 (University of Tasmania, Geology Department collection).

    (A) dorsal view, XI

    (B) ventral view, XI

    (C) lingual view, XI

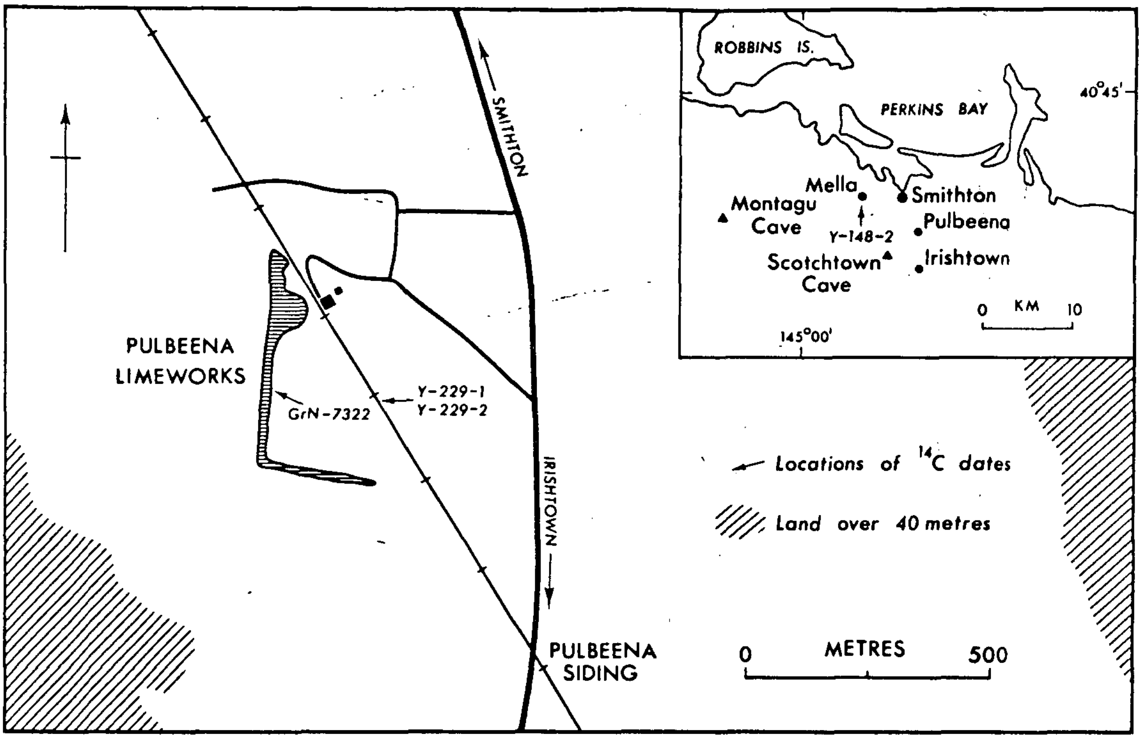
    (D) labial view, XI

3. (A) Right mandible of *Palorchestes azael* Owen;
U.T.G.D. 94271, 94272 - labial view, X½.

    (B) lingual view, X½.

    (C) occlusal view of teeth, X1.

4. Pollen ratio curves.


ROBBINS IS.
PERKINS BAY
40°45'
Mella
Smithton
Montagu Cave
Y-148-2
Pulbeena
Scotchtown Cave
Irishtown
0 KM 10
145°00'
SMITHTON
PULBEENA LIMEWORKS
GrN-7322
Y-229-1
Y-229-2
IRISHTOWN
Locations of 14C dates
Land over 40 metres
PULBEENA SIDING
0 METRES 500

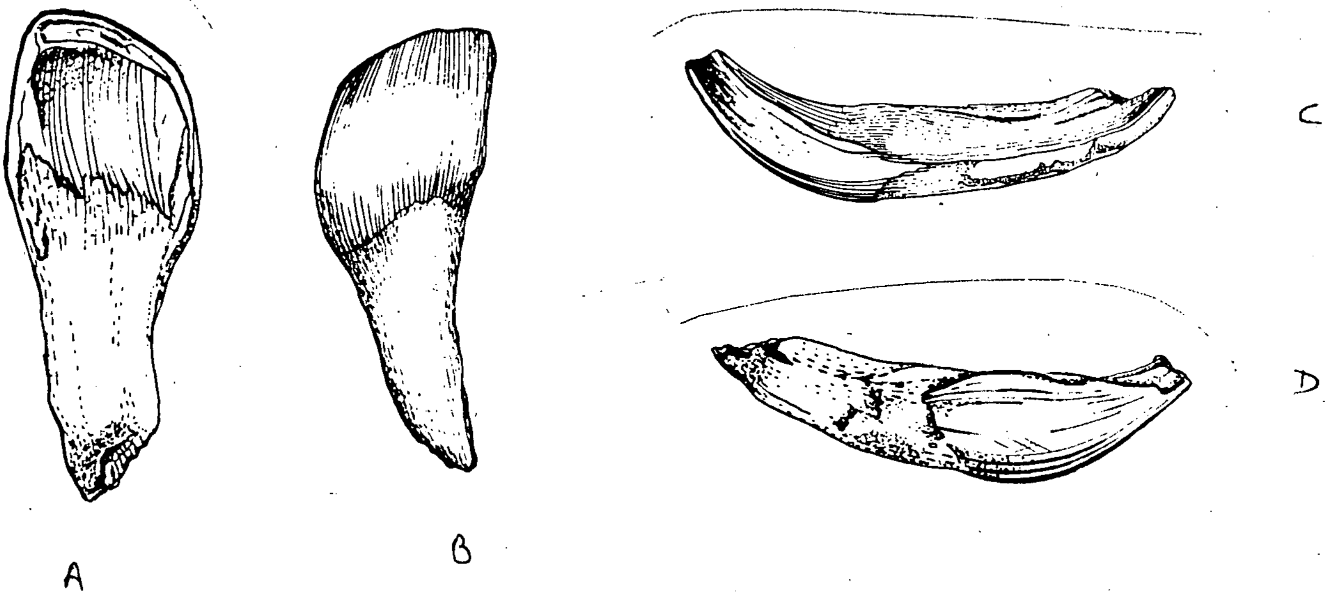


FIG. 2

BANKS, COLHOUN, GOEDE & VAN DE GEER

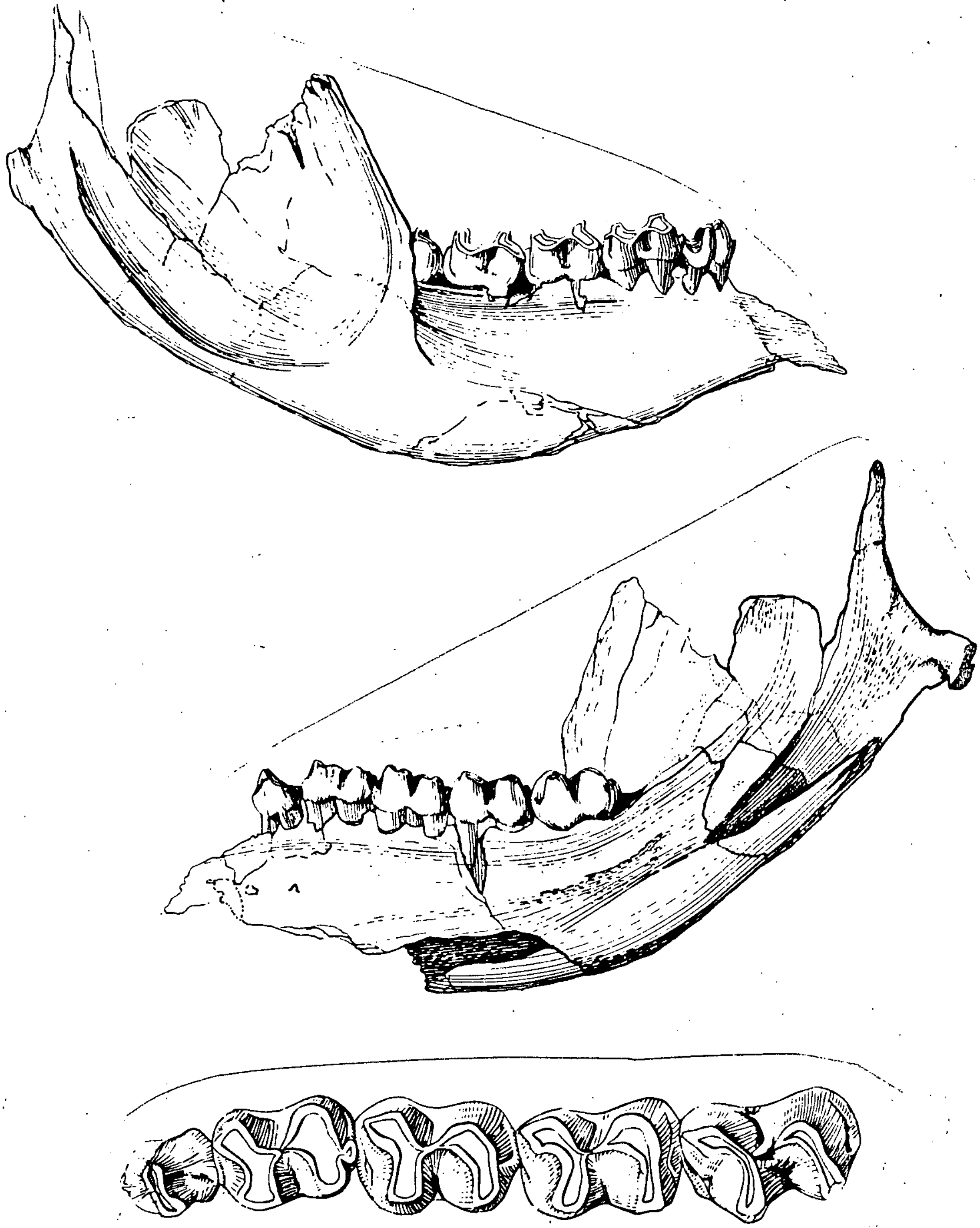
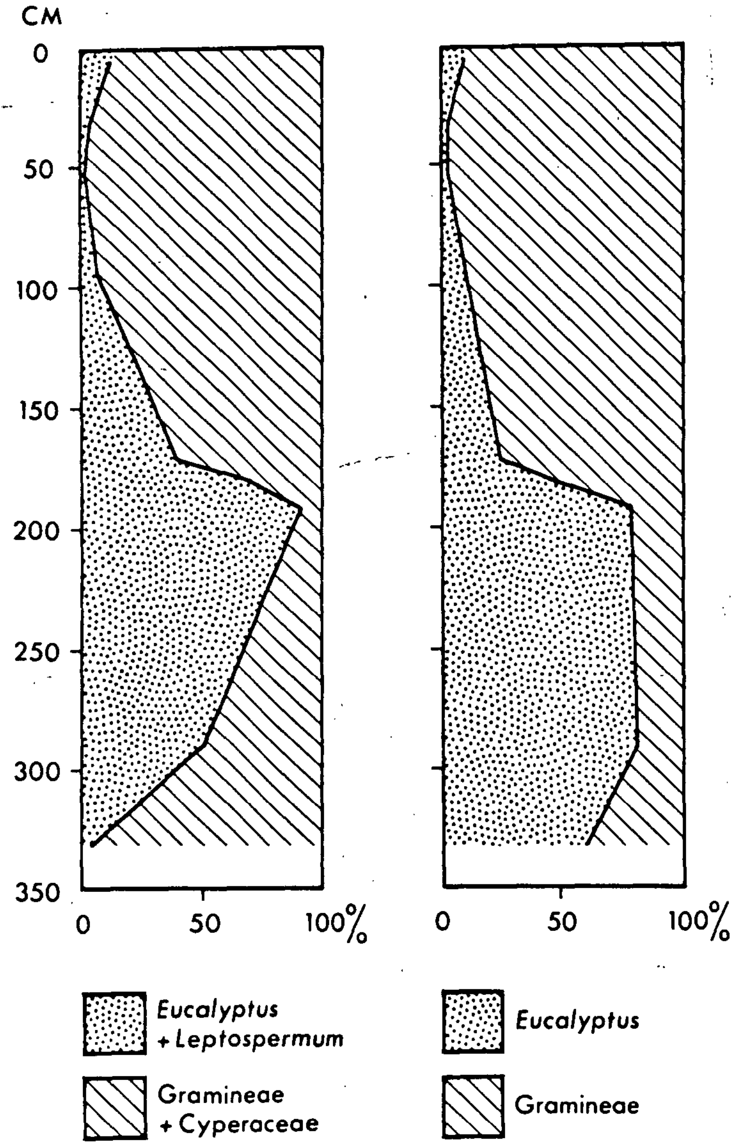


FIG. 3

BANKS, COLHOUN, GOEDE & VAN DE GEER


CM
0
50
100
150
200
250
300
350
0
50
100%
0
50
100%
Eucalyptus
+ *Leptospermum*
Gramineae
+ Cyperaceae
Eucalyptus
Gramineae

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THE PLEISTOCENE GLACIAL HISTORY OF TASMANIA

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Abstract. A. N. Lewis's scheme of Tasmania's Pleistocene glacial history in terms of three full glaciations —Malanna (ice cap), Yolande (valley glacier) and Margaret (cirque glacier)—is criticized on a number of specific and general grounds. The area reliably known to be glaciated is thought to be much smaller than Lewis claimed. Future work on Tasmanian glaciations should not be grafted on to Lewis's scheme and should aim especially to provide more reliable evidence for distinguishing and evaluating the glacial phases.

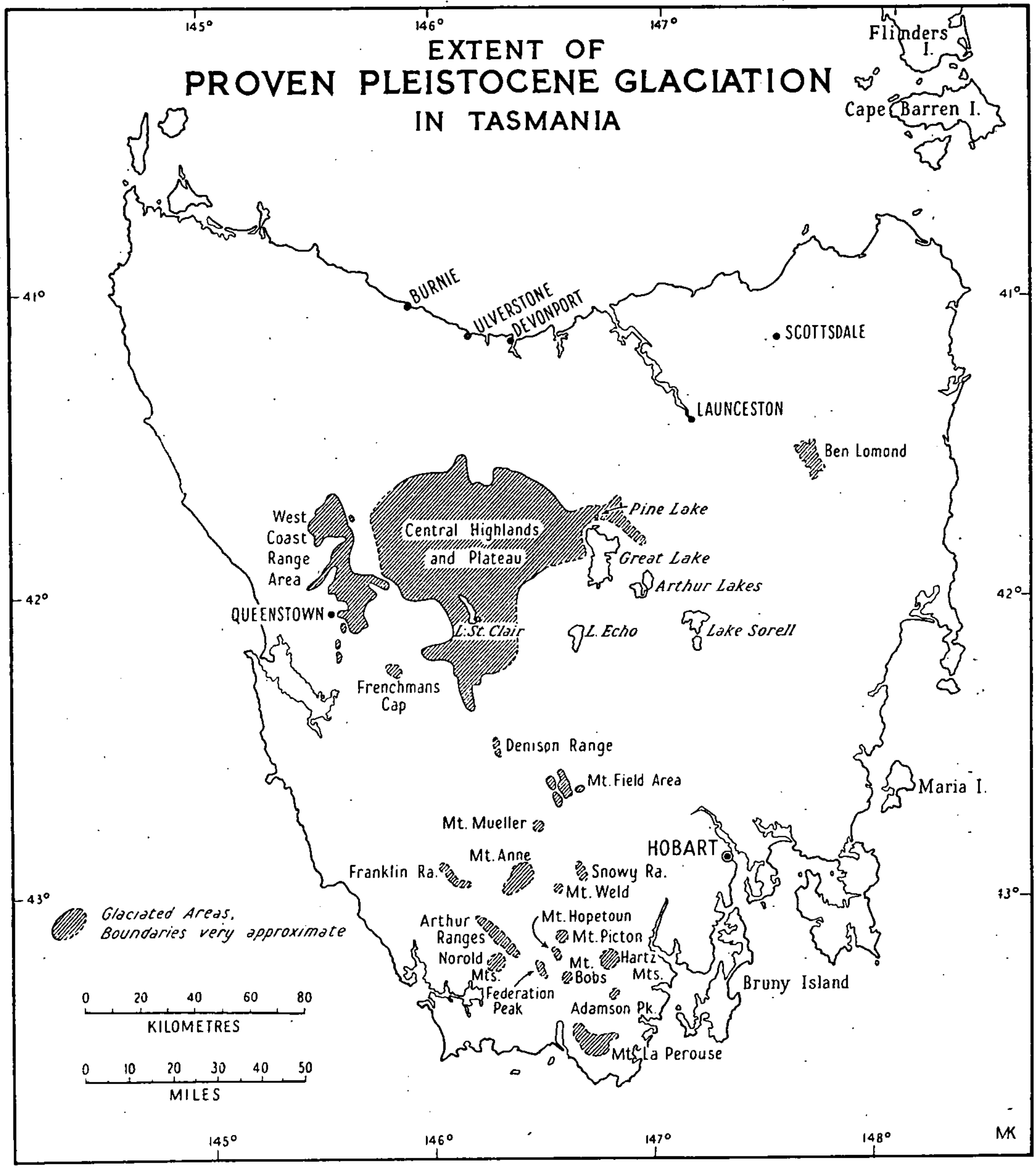
Zusammenfassung. Das System von A. N. Lewis Glazialgeschichte des Pleistozän von Tasmanien in Form von drei vollkommenen Vergletscherungen—Malanna (Eiskappe), Yolande (Talgletscher) und Margaret (Kargletscher)—wird an Hand einer Anzahl spezifischer und allgemeiner Gründe kritisch behandelt. Das zuverlässig bekannte Vergletscherungsareal wird für viel kleiner gehalten als von Lewis angegeben. Weitere Arbeiten über die Vergletscherungen von Tasmanien sollten nicht auf das System von Lewis aufgepfropft werden und sollten ganz besonders darauf hinarbeiten zuverlässigere Beweise zur Unterscheidung und Bestimmung der Glazialphasen zu beschaffen.

Recently in this *Journal* Dr. W. R. Browne [1] has succinctly presented afresh the picture of the glacial history of Tasmania, which over a long period A. N. Lewis built up in a series of pioneering papers, the product of strenuous spare-time field work in difficult country. It may seem invidious to criticize certain aspects of this work without at the same time being able to offer a well-validated framework in its place. However, whilst valuing Lewis's recognition and identification of glacial phenomena in various parts of Tasmania without the help of the air photographs, contoured maps and jeeps available now, we wonder, in the light of recent work (much of it not known to Dr. Browne when he wrote his paper), whether the scheme in which Lewis placed his observations is not now a hindrance to further progress.

That scheme consisted of three glaciations—Malanna, Yolande and Margaret—which were regarded as full glacial periods and constituted also a series of declining intensity of glacial activity, ice caps characterizing Malanna, valley glaciers Yolande and cirque glaciers Margaret. Lewis and Murray [2] suggested a fourth D'Entrecasteaux phase but afterwards Lewis [3] included this as a retreat phase in his Malanna glaciation. The Yolande was thought to consist of two distinct phases. Originally the three glaciations were correlated with the Mindel, Riss and Würm of Europe but later Lewis [4] abandoned his attempt at correlation though he was not consistent in this (*cf.* for instance Lewis [5]). Dr. Browne does not repeat the intercontinental correlation which rested on little evidence. However by employing the term Stage for the three glacial phases, he does imply, following Flint's usage, that they have the status of full glaciations.

Certain specific criticisms will now be directed against Lewis's scheme, followed by some more general argument.

(1) In the type area of Malanna, Banks and Ahmad have recently examined afresh the supposed tills and associated sediments—sand, clay and lignite—attributed to that glaciation. The details of the stratigraphy and the views of J. W. Gregory and T. W. E. David, both of whom considered tills present, will be discussed elsewhere. Here it must be briefly stated that Banks and Ahmad take the view that no evidence of glaciation is present, all the observed facts being explainable by repeated late Tertiary faulting and the development of fault scarp scree breccias, and fluviatile, lacustrine and paludal deposits in the lowland produced by the faulting. Dolerites are now known to occur near Firewood Siding



so there is no need to think that the dolerite boulders are glacial erratics from Mt. Sedgwick; the faults in the Permian beds at Firewood Siding are normal downthrows to the south-west, not thrusts from the east due to supposed ice pressure; the flattened faces of many dolerite and sandstone blocks are not glacial soles but simply the result of jointing; Owen Conglomerate boulders do not occur in the supposed till as might be expected if it is the product of ice from the east.

In addition glacial deposits near Strahan, which were regarded by Lewis [6] as due to the Pleistocene Malanna Glaciation, are considered by Banks and Ahmad to be Permian in age mainly because of the degree of lithification and the absence of Owen Conglomerate boulders. Moreover other beds at Strahan taken by David and Lewis to be glacio-fluvial outwash gravels, consist of gravels, sands, clays and lignites, with abundant evidence of stream, lake and swamp origin but yielding no evidence of glacial derivation (nor estuarine as Bradley [7] suggested). These beds were deposited in a Late Tertiary graben against the Permian glacial beds; they have since been tilted and cut into a series of terraces by marine erosion at different levels (J. L. Davies, personal communication).

In the whole of the Henty Peneplain west of the West Coast Range, which can be considered as the general type area of the Malanna Glaciation, Bradley [7] recorded glacial features only on the Henty River down to 86 m. above sea level about 24 km. inland and on the higher parts of the Yolande River further inland. Outside the limits shown on Bradley's map of the Yolande River sheet no signs of glaciation are known.

(2) Lewis [8] ascribed the varves at Gormanston near Queenstown to the Malanna Glaciation, the lake in which they were deposited being embanked by Malannan moraine. Recently a fossil wood specimen from these varves has been subjected to a carbon-14 assay which gave the date of $26{,}480 \pm 800$ years (Gill [9]). Gill also quotes K. E. Caster's opinion based on considerable experience of the North American Pleistocene that there is nothing in the degree of preservation of the associated moraines to prevent their being of Wisconsin age. If Lewis's Malannan attribution is accepted, this evidence reduces the three phases to substages or stadia of a single glaciation. However the Linda Moraine at Gormanston responsible for the lake is as fresh in its topography as the moraines near Lake Margaret (called the Hamilton Moraine of Dunn and David but later apparently the Margaret Moraine of Lewis). So that if one adopts Lewis's scheme as a whole, it is better to attribute the Gormanston features to his Margaret Glaciation. In the one way or the other, Lewis's interpretation of this area needs drastic modification.

(3) Lewis and Murray [2] considered that good evidence of separate phases of glaciation occurred near the head of the D'Entrecasteaux River. Here they describe a "peculiar button-grass covered . . . spur", an older moraine, which had its northern end cut off by a glacier and had a later moraine deposited against it. The former moraine is the type feature of the D'Entrecasteaux phase mentioned above and the latter is said to be Yolande. However air photographs now make clear that this spur does not have the physiographic form of an end moraine but descends in a series of structural benches carved from the almost horizontal Permian rocks. The variety of rock types found in surface boulders is entirely represented in the bedrock succession in the ridges above and the surface material present is regarded as scree or periglacial solifluction material. The younger moraines are present. However the main line of evidence advanced by Lewis and Murray for superimposition of glacial phases here is considered invalid and capable of a very different interpretation. The flat-bottomed cross section of the valley lower down is a structural, not a glacial, effect and the morainal character of the deposit of quartz pebbles and basalt boulders at Leprena is not considered to be clearly established.

(4) The western part of the Central Plateau has recently been re-examined geomorphologically (Jennings and Ahmad [10]); in their view there is evidence here for only one glaciation. This was an ice cap glaciation with associated outlet glaciers. Some small cirques within the area are attributed to the advancing hemicycle of this glaciation. The high degree of preservation both of *roches moutonnées* and of moraines implies that the glaciation involved must be very young and is tentatively regarded as Würm. The region studied however includes areas ascribed by Lewis to each one of his three glaciations.

The ice cap glaciation cannot be attributed to Malanna because it is too fresh in its results; soils have not formed over much of its area of erosion. If it is ascribed to Margaret, it is totally out of keeping with the slight intensity of glacierization which Lewis attaches to that last glaciation. If it is regarded as Yolande, there is less discrepancy on the side of degree of glacierization, but it has the corollary that Margaret becomes a substage of the Yolande Glaciation (*cf.* Flint [11, 12]).

(5) It is regrettable in view of the later wide use of the terms that Lewis was not more precise in defining the Yolande and Margaret phases in their type areas. Nowhere in his work is it clear just what features are to be regarded as Yolande phase in the Yolande River area nor what is Margaret in the area of Lake Margaret. To date no one has produced clear evidence of two epochs of glaciation in this area for, although Bradley [7] states that the lower Yolande moraine could have been formed by a small tongue of ice advancing *after* the formation of the bulk of the Margaret moraine, it is possible that all the features in the area are the result of the one glaciation as indeed Bradley suggests. In view of the lack of precision in the definition of the phases in the type area and the marked possibility of their being part of the one glaciation, it might perhaps be best at this stage to discard the names completely.

(6) Lewis gave little recognition to the action of periglacial processes in Tasmania. Davies [13] has shown that "Malannan moraine" on Mount Wellington (Lewis [14]) is in fact periglacial solifluction material and thinks it probable that similar confusion has taken place elsewhere.

The extent of the glaciation as mapped in Lewis [3] and reproduced in its essential features by Dr. Browne [1] is much greater than reliable evidence warrants. There is now, for example, no place known where ice reached the sea. The area between the mouth of the Pieman River and Macquarie Harbour shows no sign of glaciation closer than 26 km. from the coast. Port Davey as Dr. Browne noted is no longer regarded as a fjord but as a drowned river valley (Baker and Ahmad [15]) and there is no evidence for glaciation in southern Tasmania approaching more closely to the sea than 8 or 9 km. The area near the mouth of the Pieman River has recently been re-examined by Twidale [18] who finds no direct evidence of glaciation in the area. Jennings and Ahmad [10] indicate that the extent of ice in the Central Plateau is less than supposed by Lewis. No signs of glaciation have been found on Mt. Barrow and Mt. Victoria in the north-east. In general it seems that an ice sheet occurred only in the Central Plateau with cirque and valley glaciers elsewhere (see Fig. 1).

In one of his papers,[6] Lewis stated "Cirque erosion and not morainal deposits form the only sure guide to differentiate the various stages", and it is clear that this standpoint lies behind much of his interpretation. Most workers in the field of glacial geology and geomorphology would take the opposite point of view and it seems to the present writers that it was this standpoint which misled Lewis at various junctures. Thus the separation of a high cirque phase (later called Margaret) from a valley glacier phase (later called Yolande) which was itself divisible into two, goes back to his initial studies of the Mt. Field National Park.[16, 17] In the Broad River valley, the moraine-dammed Lake Webster is backed by a "cirque" which rises 90 m.; at that level there is Lake Seal, another moraine barrage lake, which heads in another "cirque" with a backwall 300 m. high. Above this backwall is the Tarn Shelf, a sort of elongated cirque, with several small lakes, rock-basined as well as moraine-dammed. The three "cirque" levels are related by Lewis to three levels of maximum frost action belonging to different glacial phases and the erosional work is regarded as having been performed successively. However, there seems to be no reason at all why the two lower "cirques" are not to be regarded as steps normal in a glaciated valley, pre-glacial steepenings in the valley gradient accentuated by the well-known peculiarities of glacial erosion. All the erosional features can surely be the product of a single glacial period with a valley glacier occupying the whole valley; the various moraines may represent halts in the retreat of this one glacier.

The test of the comparison of deposition in the form of the volume of moraines with the amount of rock evacuated to form the cirques is not applied by Lewis. Thus the moraines on the Tarn Shelf seem much too meagre to balance the erosion at that level. It seems more in keeping with the facts to think of the Tarn Shelf as the work of a hanging glacier on a structural bench feeding a contemporary glacier below in the Lake Seal valley. The degree of glacial rounding of the lip below the Tarn Shelf is consistent with such an idea although no doubt windows in the ice exposed the rockwall to frost action for long periods.

Lewis failed to note the significance of the overriding by ice of the backwalls of cirques. Cirques are just as likely to be formed in the advancing hemicycle of a glacial period as in the retreating phase (*cf.* Charlesworth [19]). Thus there are a number of small cirque-like features on the western Central Plateau; yet almost without exception they were overridden by the ice cap and the lips of their backwalls are rounded by glacial abrasion (Jennings and Ahmad [10]).

Moreover the likelihood that regions peripheral to an ice cap will carry valley glaciers and cirque glaciers is strong and the work of outlet glaciers from an ice cap may be difficult to distinguish from that of valley glaciers. These are considerations which seem to allow of different interpretations for many of the glacial phenomena of which Lewis furnished pioneer descriptions. Thus it is clear that the ice cap of the western Central Plateau provided much of the ice which went to swell the might of the great piedmont glacier responsible for the 210 m. deep Lake St. Clair and the great festoons of fresh moraine ridges around the lake foot. Nor does there seem to be any evidence against the view that the glacial horn of Mt. Ida on the eastern shore of this lake is the product of this same ice cap phase. The neighbouring "cirques" which Lewis ascribes to the Margaret Glaciation show every sign of the deluge of ice from the plateau behind. Moreover the level of these "cirques" is over 300 m. below that of the opposing Margaret cirques high on the east face of Mt. Olympus and is therefore well below the altitude generally attributed to the Margaret Glaciation in this area.

Lewis's scheme of three glaciations each characterized by a type of glacier—ice cap, valley glacier, cirque glacier—is inherently unlikely over areas such as those involved in Tasmania, with their strong climatic gradients and wide variety of terrain ranging from highly dissected country to virtually untouched plateau. Such a simple scheme can no doubt fit the waning phase of a single glaciation in Tasmania or represent the full Pleistocene history of a single *massif* such as the Kosciusko region on the mainland. But for the whole glacial history of Tasmania a more complex picture is likelier, with combinations of all three types as the changing snow line brought varying extents of land in differing climatic and topographic contexts within its grip. This may be the major reason why Flint in his world survey of the Pleistocene [11, 12] has been disinclined to accept Lewis's views completely.

To construct a glacial history from the erosional results of ice work is difficult; the moraines which Lewis relegated to second place can tell us more from detailed analysis of their degrees of weathering and dissection, from examination of their erratic content and fabric revealing different movements and sources, from buried soils and weathered surfaces where tills are superimposed. Most of all should attention be given to the search for organic deposits interbedded with moraines or at least having significant distributions in relation to different moraines.* Palynological investigation and C-14 dating are the chief means whereby glacial advances and retreats can be reliably regarded as stadial phases or full

* Loftus Hills (in Lewis [14]) reported peat between two moraines on the Central Plateau at a site now beneath the waters of the Lake Augusta reservoir. It could imply anything from a retreat of a few hundred yards to a full interglacial.

glaciations. Meanwhile until such evidence is forthcoming, Lewis's chronology with doubts cast on its three type areas and a certain degree of improbability in its general nature, should not be regarded as a mould into which detailed studies of glaciation in different parts of Tasmania should be fitted.

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~~Dr Barry Scott~~,
with best wishes
Max Banks

NOTES ON THE CAINOZOIC HISTORY OF WESTERN TASMANIA—"MALANNA" GLACIATION

by

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NOTES ON THE CAINOZOIC HISTORY OF WESTERN TASMANIA— "MALANNA" GLACIATION

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(With 4 Text Figures)

ABSTRACT

The Cainozoic history of the Malanna area ncluded faulting, deposition of sediments by treams or in lakes and swamps, two epochs of lanation, and stream erosion. There is no hysiographic, depositional or structural evidence or glaciation in this area, the type area of ewis's Malanna Phase of the Pleistocene glacia-ion. This phase must be considered invalid on he evidence available in the type area and the erm " Malanna Phase " should be abandoned.

INTRODUCTION

Gregory (1904, p. 51) first described the sedi-nents near Malanna which were later considered o be morainal and adopted by Lewis as the type eature for his Malanna Glacial Phase of the Pleistocene glaciation. Gregory considered them to e glacial because of the presence of boulder clay ontaining boulders of very decomposed dolerite. Because of the depth of weathering of the boulders nd " lack of indication of recent glaciation in this ocality ", he provisionally assigned a Carboniferous Permian of present day nomenclature) age to the laciation. Later Loftus Hills showed these deposits o David, who was impressed by the shattering f the Permian rocks at Malanna and influenced y the flat-floored, steep-walled valley of the Eden Rivulet (now Badger River) and perhaps also by he morainal form of some of the hills near Fire-vood Siding and Koyule (see Fig. 2). David (1926) lso considered the deposits near Malanna to be lacial and, because of the impressions he had ained of the physiographic effects of glaciation, e considered them to be Pleistocene. On the rounds of depth of decomposition of the dolerite oulders and amount of river erosion since the upposed glaciation he considered that the " Mal-nna Moraine is at least as old as Mindel, and ossibly even as old as Günz ". The presence of olerite boulders, the lack of known outcrops of olerite in the neighbourhood and the supposed laciation forced David to postulate transport of olerite from Mount Sedgwick, twenty miles away, y an ice sheet, as Mount Sedgwick was, and still is, the nearest known dolerite-capped mountain showing glacial effects. In 1934 Lewis designated these deposits as the type evidence for his Malanna Phase.

Gill and Banks (1950) visited the area and made observations on the older rocks. In 1953 K. G. Brill, G. E. Hale and M. R. Banks visited the area and K. G. Brill made the important discovery that there was a large outcrop of dolerite less than one mile north of Firewood Siding, and less than half a mile from the nearest "morainal" deposit. Detailed sections were measured in some of the cuttings. In 1957 the present authors visited the area in an attempt to solve the outstanding problems connected with the glaciation but, after a few days further observation, concluded that there was no evidence at all for Pleistocene glaciation in this area and that all the features could be produced by Tertiary faulting and normal erosion.

Method of Measuring Heights

Heights quoted along the railway line and south of the Henty River are those for a series of survey pegs which were established by R. Braybrook, Hydro-Electric Commission surveyor, as part of an air-photo control survey. The heights of the survey pegs are related to mean sea level at Hobart. The four heights not on the railway line were measured in 1957 by an aircraft altimeter capable of reading to ten feet. The heights were found by reading on the survey pegs, then on the various physiographic features and then onto the same or another survey peg. Maximum time between successive readings on survey pegs was twenty minutes.

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PHYSIOGRAPHY

The Malanna area is situated north of the mouth of the Henty River, a couple of miles inland from the western coast of Tasmania (see map, fig. 1).

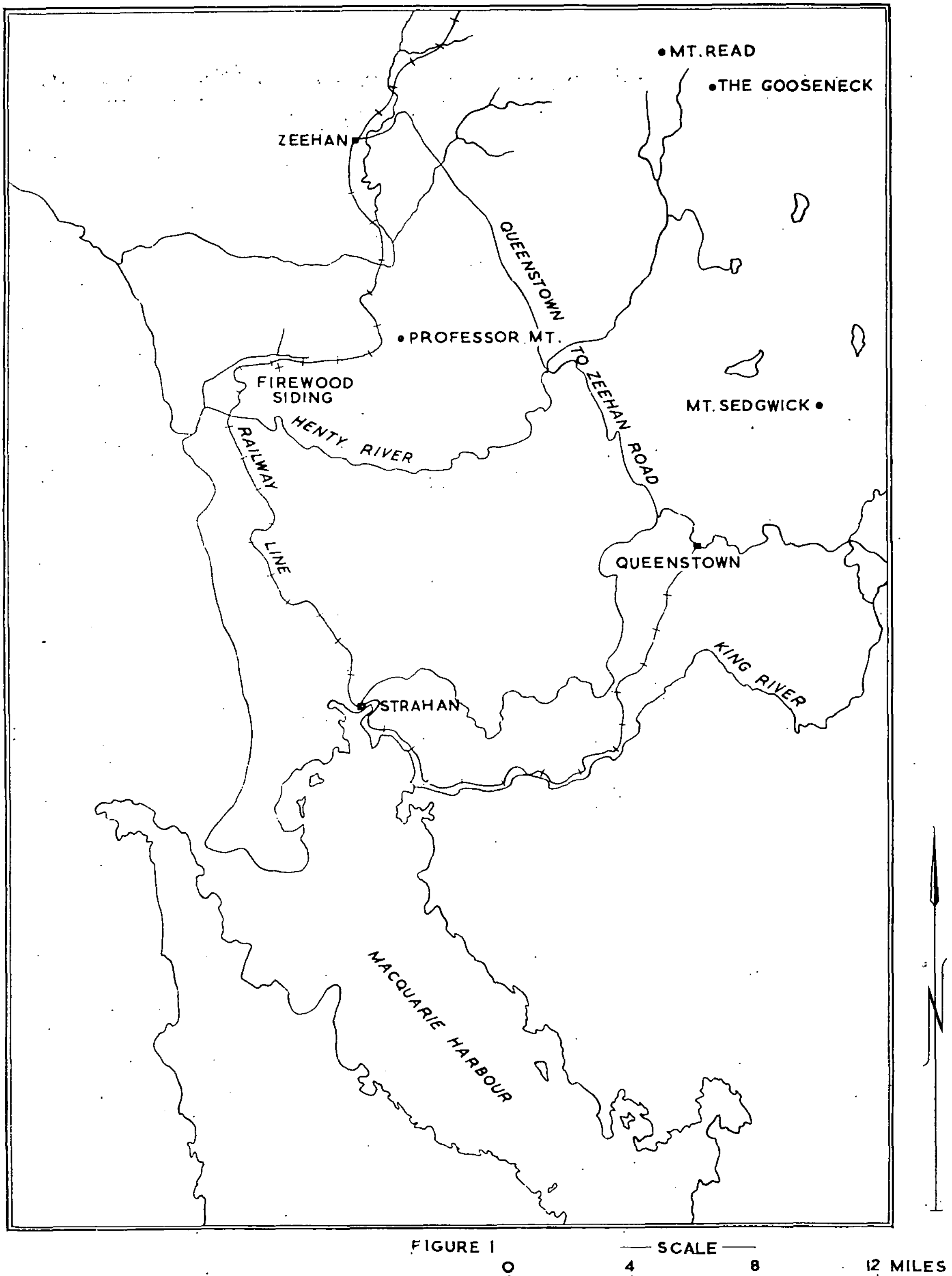

MT. READ
THE GOOSENECK
ZEEHAN
QUEENSTOWN TO ZEEHAN ROAD
PROFESSOR MT.
FIREWOOD SIDING
HENTY RIVER
MT. SEDGWICK
RAILWAY LINE
QUEENSTOWN
KING RIVER
STRAHAN
MACQUARIE HARBOUR
N
SCALE
0
4
8
12 MILES

FIGURE 1

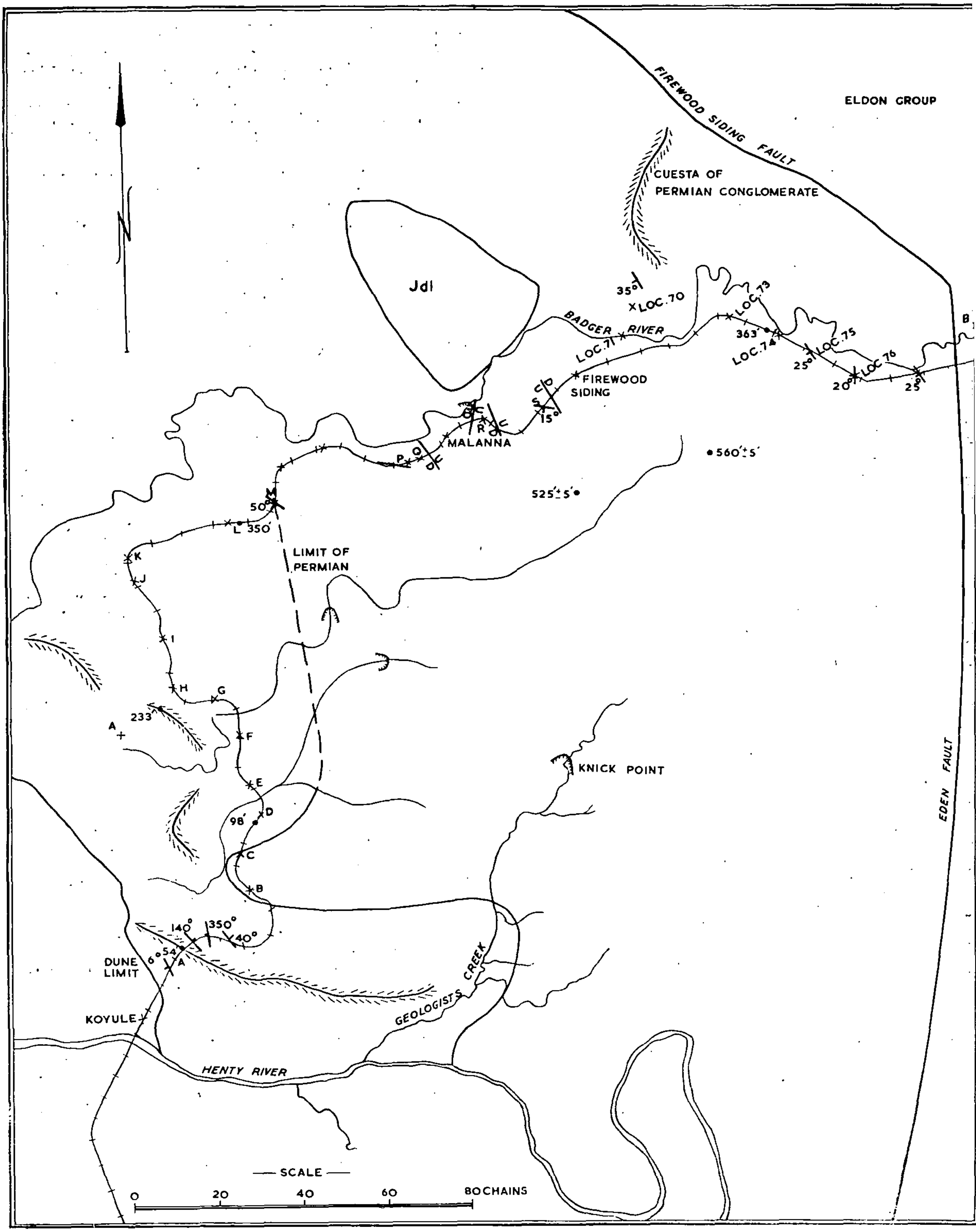
The main drainage of the area is by the Badger River to the north and the Henty River to the south. The Badger River rises about four miles to the east on the western slope of Mount Professor (see Gill and Banks, 1950, pl. III). From its source to about half a mile east of Firewood Siding the river flows in a swampy plain about half a mile wide which has a height of about 360 feet above sea level about a mile east of Firewood Siding. The plain lies between steep scarps on both sides and the river flows mainly near the western or northern boundary of the plain (see Gill and Banks, 1950, pls. I and III). There is one low, sharp ridge on the plain which parallels the western and northern wall and is about twelve chains from it. The main tributaries above Firewood Siding enter the Badger River from the east and south and are approximately at right angles to the scarp bounding the plain. In this part of its course the western and northern scarp is in Crotty Quartzite, the river plain in Gordon Limestone with a sandy band in it which is represented topographically by the small ridge on the plain, and the eastern and southern scarp a dip slope in Owen Conglomerate and Caroline Creek Sandstone. From its source to about half a mile east of Firewood Siding, the Badger River and its tributaries are strongly structurally controlled; the river follows the strike of the Gordon Limestone and the tributaries are perpendicular to the strike around the noses of a north-west-plunging anticline and syncline. Only minor streams join the Badger River from the scarp of Crotty Quartzite. The Badger River is separated at its source in the north by a low divide from a stream cutting down through the Crotty Quartzite and finally flowing into the Little Henty River. The divide is within the plain and is only a few feet high. After crossing the Eden Fault (see fig 2) half a mile east of Firewood Siding the Badger River enters a valley tract (of Hills, 1946) in which it is cutting into Permian rocks. The main tributaries now enter from the north and are more or less parallel to the strike of the Permian rocks. About thirty chains west of Firewood Siding the river enters a mountain tract (of Hills, 1946) in which it is entrenched in the sandstones of the Cygnet Coal Measures. Further downstream the relief is lower but the stream still in mountain tract until about one and three quarters of a mile west-south-west of Firewood Siding it opens out into a valley tract before turning south and flowing between vegetated dunes to the east and intermittently moving dunes to the west.

Loftus Hills is credited by Lewis (1926, p. 88) with the discovery of a small glacial valley superimposed on a broader glacial one in the Eden Valley. David (1926, p. 91) implies that the Eden Valley (now Badger Valley) had suffered "very ancient glaciation", but in neither case was any detailed physiographic evidence offered. At first sight, the Badger Valley might appear glacial because of the steep side slopes, the flat floor and the gentle curve of the valley in plan. These features of the valley are the result of normal atmospheric and stream erosion in a topography of rocks of varying competence, the incompetent Gordon Limestone lying between the resistant formations, Owen Conglomerate and Crotty Quartzite. A local base level developed in Permian rocks, just east of Firewood Siding, has caused the erosion to that level of the Gordon Limestone in the Badger Valley. The entrenchment of the Badger River west of Firewood Siding may be due to rejuvenation, possibly associated with faulting or fall in sea level, with headward movement of the knick point (see fig. 2). The Badger River valley shows no physiographic evidence of glaciation.

The main stream draining the area is the Henty River, which rises about sixteen miles to the north-east on the slopes of Mount Read and the Gooseneck and flows through the Henty Surface as an entrenched, youthful stream to within a mile or two of the Malanna area. It is still in mountain tract to within a mile of the railway bridge, but below this shows some depositional features near present river level. The Henty River north of the Queenstown-Zeehan Road is glaciated and the terminal moraines of the glacier which occupied the Henty Valley occur a few hundred yards below the road bridge over the Henty River (Bradley, 1954, p. 196, and Yolande River Sheet). The exact level of the foot of these moraines is not known but it is probably not more than forty feet below the bridge which has a height of 282 feet above sea level (H.E.C. Bench Mark). Below these moraines the Henty River is in a typical mountain tract and there are no further signs of glaciation.

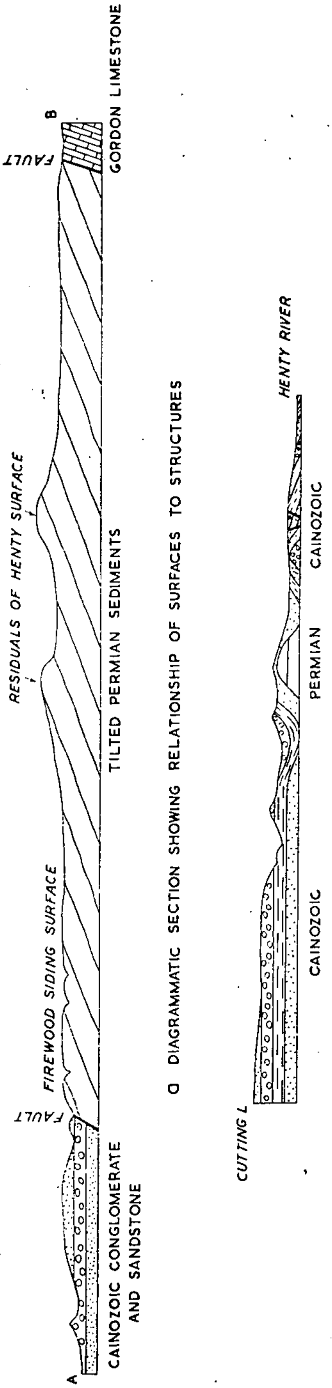
The area between the railway line and the Henty River is drained by west-flowing streams and by Geologists Creek. In all cases the headwaters are in wide, low valleys and swampy conditions are common. Further down their courses the streams pass into steep, narrow, mountainous valleys before entering short valley and plains tracts prior to joining the Badger or Henty Rivers.

The surface topography of the area might, perhaps, be considered in terms of a number of erosional surfaces. The highest of these is the Henty Surface (of Gregory, 1903; not Bradley, 1954). This extends from the foot of the West Coast Range, where it has a height of from 1,100 to 1,200 feet above sea level, to the Malanna area. In the Malanna area a height was measured on a hill of Crotty Quartzite (Gill and Banks, 1950, pl. I, western photo, 1.5 cms. S.W. of centre point) which forms part of this Henty Surface. The height is 720 (± 10) feet above sea level, giving an average slope to the sea of about 60 feet per mile. Immediately south of Firewood Siding the heights of two hills in Permian sandstone and conglomerate were measured and found to be 525 (± 5) and 560 (± 5) feet (averaged figures) above sea level. The higher, easternmost one, is about two miles from the hill of Crotty Quartzite measured and the seaward slope is of the same order as that for the main part of the Henty Surface. North of Firewood Siding a sharp ridge of Permian and a hill of dolerite appear to reach a similar height to the hills south of Firewood Siding and to be accordant with flat-topped hills to the north, forming part of the Henty Surface. Thus the hills immediately south of Firewood Siding are considered to form part of the Henty Surface.



ELDON GROUP
FIREWOOD SIDING FAULT
CUESTA OF PERMIAN CONGLOMERATE
Jdl
LOC.70
BADGER RIVER
LOC.71
LOC.73
LOC.74
LOC.75
LOC.76
363'
FIREWOOD SIDING
MALANNA
560'±5'
525'±5'
LIMIT OF PERMIAN
L 350'
233'
KNICK POINT
EDEN FAULT
98'
DUNE LIMIT
KOYULE
GEOLOGISTS CREEK
HENTY RIVER
SCALE
0 20 40 60 80 CHAINS

FIGURE 2



a DIAGRAMMATIC SECTION SHOWING RELATIONSHIP OF SURFACES TO STRUCTURES

b. STRUCTURE OF CAINOZOIC SEDIMENTS AS SHOWN IN RAILWAY CUTTINGS PROJECTED ON TO SECTION BETWEEN CUTTING L AND RAILWAY BRIDGE OVER HENTY RIVER

FIGURE 3

Sections of Malanna Area showing Physiography and Structure

Between these hills and the Henty River is a flattish area cut in dipping Owen Conglomerate and tilted Permian sediments. This rises abruptly along steep scarps to the north and falls abruptly to west and south along steep scarps. To the east it continues across Permian rocks and the Junee Group until it reaches a more resistant bed in the Owen Conglomerate which forms a steep dip slope about one and three quarters of a mile south-east of Firewood Siding. This surface is drained by wide, flat valleys. It is an erosional surface truncating the tilted rocks (see figs. 2 and 3). No heights have been measured on this surface, but from ground observations it would appear at its north-western end to be a few feet lower than the top of the Tertiary sediments (350 feet above sea-level). It rises somewhat to the east where it is a little higher than the height of the Badger River plain about a mile east of Firewood Siding, i.e., about 360 feet above sea-level. This surface at from about 350 feet to about 400 feet might be called the Firewood Siding Surface. Separating this surface from the present plain of the Badger River is an east-facing obsequent fault-line scarp of the Eden Fault about 40-50 feet in height. The plain east of this scarp is in Gordon Limestone that to the west in more resistant Permian mudstone and sandstone. Another flattish area occurs on the northern side of the Badger River north-west of Malanna. This also is eroded in tilted Permian sediments and is at about the same level as the Firewood Siding Surface.

The sharp ridge north of Firewood Siding is a compound one as a fault appears to pass across it near its southern end. Near the southern end it is made up of two connected cuestas, but a structural control for its northern end is not clear. The hills south of Firewood Siding forming part of the Henty Surface have steep southerly-facing scarps and gentler, although still steep, northern slopes. The southern scarp is a cut-off scarp of the creek shown on the map (fig. 2) now dissecting the Firewood Siding Surface. The northern slope is not a dip slope as shown by numerous dip readings in the Permian rocks in the railway cuttings.

On the hills east of Henty Siding, a siding about a mile south of the railway bridge over the Henty River, there are exposures of gravels containing large blocks of Permian sandstone and dolerite. These form part of a surface at about 300 feet above sea level. The hill west of cutting H has a height of 235 (± 5) feet above sea-level, and is more or less accordant with the hills immediately to north and south. The maximum height reached by the Tertiary sediments (in Cutting L, fig. 2) is 350 (±5) feet above sea-level.

Further west is a low sand-covered area, now vegetated, and beyond this an area of active dunes.

The two surfaces in the area, the Henty Surface and the Firewood Siding Surface, show no signs of glaciation in this area. The Firewood Siding Surface is shown on Gregory's map (1903, pl. XX) as part of his Western Peneplain. On neither surface are there any erratics locally, no ice polished, nor ice-scoured surfaces, and no sign of ice plucking. Although David noted roches moutonnées in the Eden Valley, he gave no details and the present authors are unable to find any. There are no signs of the passage of ice over any of the scarps and some of the ridges, e.g., that just south of Firewood Siding containing the measured hills, have steep irregular faces to the east (the alleged direction from which th ice sheet came) and a more gentle slope to the west. The sharp-crested ridge north of Firewood Siding is very steep sided and, in plan, convex to the west. It could, on superficial examination, be mistaken for a moraine, especially as it has blocks of rock scattered over its surface. However, detailed examination of this ridge shows it to be, at least partially, a cuesta in Upper Permian quartz sandstone and conglomerate and the scattered boulders to be entirely of these materials.

The Firewood Siding Surface is succeeded to the west and south by an area of lower hills (see fig. 3, *a*). Just south of the Badger River is a south-east-trending fairly-sharp-crested ridge cut by a south-westerly-flowing stream. In many places the crest of the ridge is demonstrably pebbly. Its height is 235 (± 5) feet above sea-level. South of the end of this ridge and separated from it by a deep valley is a sharp-peaked hill with a slight tendency to a south-south-westerly trend then a swing to the south-east. No outcrop occurs but boulders and pebbles are spread over the surface. This is separated by a creek valley and a swampy flat from a ridge which is cut by the railway line just north of Koyule and trends east-south-east. The surface of this ridge is gravel-covered, but the railway section reveals the presence of other types of sediments. It is clear that the ridge is not a depositional feature and, where cut by the railway line, it is anticlinal in structure. A superficial examination of these ridges may well suggest terminal moraines, more or less convex to the sea, later breached by streams. However, the section through the southern one clearly shows that it is not morainal and sections in railway cuttings just behind the others suggest the same. These considerations, together with a lack of glaciation in the hinterland, indicate that these ridges are not moraines. Thus, in the Malanna area, there is no physiographic evidence of glaciation.

CAINOZOIC DEPOSITS

The earliest record of Cainozoic deposits in this area is that of Montgomery (1890), who noted the presence of clays in the first creek valley west of the railway bridge and near the Henty Ferry and suggested their equivalence to the Macquarie Harbour Beds. In 1892 Johnston noted the presence of lignite in the same area and recorded a *Fagus* close to *F.* (now *Notofagus*) *cunninghami* and an *Acacia* close to *A. melanoxylon*. To him the close resemblance of these two forms suggested that the lignites were "of a more recent date than any other lignite formation hitherto described". Gregory (1904, p. 51) described some of the rocks in the railway cuttings. Boulder clays with boulders of Owen Conglomerate and decomposed dolerite up to two feet across were mentioned. Gregory described the boulders as lying at all angles and having a shape characteristic of ice-action, most of them having one or more flattened surfaces. David (1926, pp. 94-95) described the blocks in the northernmost railway cutting as up five feet in diameter and all rounded, althoug elsewhere on p. 95 he states that the shape of man is obviously glacial. In a footnote on page 10 David notes that the sequence is more complex tha he had depicted. He states that the redistribute glacial beds at Henty Siding pass below sea leve are capped by lignitic shale and sandstone, an faulted.

It will be convenient to describe the deposit exposed in the railway cuttings between the railwa bridge over the Henty River and Malanna in orde from south to north.

Cutting A (see map)

At the southern end of the cutting a successio dipping 240° at 6° is exposed. At the base is bed of gravel at least twelve feet thick and consist ing mainly of rounded boulders of dolerite up t 30 inches long with some boulders of Permia sandstone, siltstone and conglomerate. Some o the boulders are sub-angular to angular. Ther is a suggestion of an upward decrease in grai size, although this is not marked. This is overlai by two feet of clayey sand and then one foo 10 inches of clayey pebbly sand with lignitic frag ments used in radiocarbon dating. This latter be of sand is cross-bedded, and contains som conglomerate bands in which there are pebbles o siltstone. In both of these sandy beds there ar branching, cylindrical ferruginous concretions whic are in some cases around lignitic fragments. Th next bed is a conglomerate composed mainly o fragments of Permian siltstone with some lignit fragments. This is 1′ 8″ thick at its northern en but thickens to the south-west and becomes mor conglomeratic in that direction. Some cross-bed ding is present in the sandy matrix and the current came from the north-east or north. This con glomeratic bed has an irregular lower surface an this forms a prominent overhang in the face o the cutting. The final bed in this succession is a least 15 feet thick and consists of gravels wit sandy lenses showing cross-bedding indicating cur rents from north-east or north. Some clay lense are also present. The main boulders are compose of Permian rocks and dolerite.

This succession is affected by two normal fault forming a small graben with a throw of a few feet Further north in the cutting the succession i hidden for an interval by sand and vegetation Beyond this gravels again occur. They are sandie than those in the southern end of the cut an contain rounded boulders of dolerite near the base with boulders of Permian rocks and Owen Conglo merate becoming more common near the top. A the extreme northern end of the cutting these ar overlain by a lignitic bed, then more gravels, sand and finally a lignitic bed. The lower of thes lignitic beds dips 50° at 40°. About half-way alon the western wall of the cut sands and interbedde carbonaceous sand or peat abut disconformabl against the gravels.

Cutting B

This cutting is mainly in Permian rocks whic are described elsewhere (Banks and Ahmad ms) The Permian rocks are overlain by a bed of grave two feet thick which, in one place near the southern end of the eastern bank of the cutting, occupies an old gully a few feet deep. The gravel is sandy and contains rounded to sub-rounded angular boulders of Owen Conglomerate, quartz, quartzite and Permian sandstone. This is overlain by about three feet of soil.

Cutting C

In this cutting Permian rocks are overlain by a couple of feet of gravel and then about three feet of soil.

Cutting D

The beds in this cutting dip 85° at 28°. At the base is a cross-bedded sandstone with some gravelly layers, which becomes lignitic and clayey towards the top. This is followed by sand and then, after a slight gap, sand with layers of peaty sand and boulders. Another cross-bedded sandstone follows. It is pale yellow-brown in colour and has rare boulders. The cross-bedding is due mainly to currents coming from the north-east. This sandstone passes up into the sandy clay, clay and then lignite. The top beds in the cutting are pebbly sands with three thin beds of boulders near the base and a bed of pebbles higher up. Cross-bedding dipping south-west is present. Boulders in these cuttings include those of Owen Conglomerate, Permian sandstone and weathered dolerite. These beds are overlain by a gravel is in Cuttings B and C.

Cutting E

At the southern end of this cutting there is a gravel with boulders up to four feet long which is rudely bedded and contains pockets of pebbles. There is a high proportion of boulders in the gravels, which range in size from a quarter of an inch up. The boulders are well rounded but the sphericity is frequently low. The boulders include those of dolerite, weather and fresh Permian rocks, including conglomerates and sandstone, quartzite, clay and Tertiary sandstone. The small dolerite boulders are completely weathered, the larger ones to a lesser extent. This part of the cutting is overlain by about three feet of soil.

To the north the gravels are overlapped by white cross-bedded, sandstones with interbedded clays and lignified wood, seeds and leaves with some pyrite nodules. Some of the larger fragments of lignified wood are still standing upright (i.e., are in growth position). The cross-bedding appears to be due to currents coming from the north-east. The succession in this part of the cutting dips 230° at 26° and is overlain unconformably by a surface gravel with boulders of Owen Conglomerate.

The succession was measured in some detail and is shown below:—

Top:

Gravel with boulders of Owen Conglomerate.
Unconformity.
18 feet: White, fine to medium grained sandstone with thin bedding.
1 foot: Coarse siliceous conglomerate with boulders of Permian sandstone.
4 feet: White, medium-grained, unbedded quartz sand.
1 foot: Coarse, siliceous conglomerate with boulders of Permian sandstone.
4 feet 6 inches: Grey clay with lignified plant remains near top and about one foot from top; top foot is fissile; some pyrite.
3 feet 6 inches: White, grey or white with red streaks, clay with cylindrical, spherical, branching and irregular limonitic nodules.
7 feet: Yellow to white, fine to medium grained sandstone, consisting of quartz with clay cement; friable; grains sub-angular to sub-rounded with a few pebbles.
5 feet: White, medium-grained sandstone with occasional bands of pebbles of Permian sandstone.
1 foot 6 inches: Conglomerate with rounded, elliptical pebbles and cobbles up to eight inches long, mainly of Permian sandstone.
1 foot: Medium-grained sandstone without pebbles.
9 feet: Sandstone with coarse bands of angular grains, with 9-inch pebble band with angular to rounded pebbles of several sizes of quartz, quartzite, Owen Conglomerate and Permian sandstone.
13 feet: Very pale, sticky clay.
4 feet: Gap in section.
6 feet 6 inches: Pale-brown, cross-bedded sandstone.
2 feet 6 inches: Clay, grey, with plant stems and some carbonaceous bands.
6 feet 6 inches: Pale-brown, cross-bedded, finely-bedded sandstone; quartzose, mostly fine-grained bed, some beds of medium to coarse grained sand; in the latter of which the grains are distinctly angular.
16 feet. Grey clay with plant stems and some carbonaceous bands.
26 feet. Sandstone, white to yellow, medium-grained, quartzite, thinly bedded.
5 inches: Conglomeratic, yellowish sandstone.
13 feet: White to pale-yellow sandstone with a few conglomeratic bands.
9 feet: Conglomerate sandstone with cross-bedding on small scale, dipping south-west; sub-rounded, sub-angular and some rounded pebbles and cobbles up to six inches long of Owen Conglomerate and Permian sandstone.

153 feet (approx.).

At the northern end of the cutting the south-westerly-dipping basal beds in the above succession are overlain unconformably by gravels with boulders of Owen Conglomerate.

Cutting F

At the southern end of this cut a fault throws cross-bedded sandstone to the south against beds of gravel and cross-bedded sand to the north. The cross-bedding dips north. The beds are almost horizontal and are from one foot to two feet thick. The boulders, which are up to three feet long are sub-angular to sub-rounded and rounded. They consist of Permian sandstone and siltstone, quartzite, quartz and dolerite. Many of the boulders are deeply weathered. The total thickness is about 30 feet. Further north again are sands containing a few large pebbles.

Cutting G

The main rock-type is a conglomerate lacking bedding and containing sub-angular to sub-rounded boulders up to several feet in diameter, with a few rounded ones. They consist mainly of Permian sandstone which is deeply leached and exfoliated. The matrix is sandy and there are some sandy bands, one of which is at least is in a washout.

Cutting H

Gravels are overlain by sands. The boulders are up to four feet long and are mainly Permian sandstone near the base but a few dolerite boulders occur near the top. The sands are cross-bedded with the dip of the cross-bedding to the south.

Cutting I

Sands at the base are overlain by lenses of gravel, followed by more sands and then gravel. The dip is at a low angle to the south. The top sands are cross-bedded with some of the cross-bedding traces in the cut dipping south-east, while most of them dip north-west.

Cutting J

Gravels with boulders more than three feet long are present.

Cutting K

The gravels in this cutting contain boulders up to five feet long. The boulders include those of Permian sandstone, and leached siltstone, with some quartz and quartzite. The gravels are interbedded with a fine-grained sand showing cross-bedding dipping north. A washout in the sands is filled with the conglomerate.

Cutting L

This is the last cutting in which Cainozoic deposits occur. They are gravels with many boulders up to a few feet long of Permian sandstone with a few boulders of dolerite.

The Cainozoic deposits exposed in the railway cuttings consist, then, of more or less unconsolidated rocks, with gravels, cross-bedded sands, clays and lignites being represented. The gravels are commonly bedded and the boulders in them are mainly sub-rounded. No striated pebbles were found, although they were looked for. The rock fragments consist mainly of Permian sandstone, siltstone or granule conglomerate, dolerite, Owen Conglomerate, quartz and quartzite and, more rarely, fragments of clay or clayey sand or lignite. Some of these boulders are now deeply weathered. It is notable that there is a general increase in grain size in the boulders from south to north, boulders up to five feet long occurring in Cuttings K and L, but all the gravels are not necessarily contemporaneous. It is also significant that the rock types present are all potentially of local derivation and could all come from within three miles to the east. The matrix of the gravels is predominantly sandy and they contain little clay.

Cross-bedding in the sands south of Cutting F dips mainly to the south-west, but north of this cutting the dip of the cross-bedding varies and tends to be northerly in several places. The presence of lignite indicates that some of the beds, at least, are paludal and no marine macrofossils were seen. There are numerous disconformities and some unconformities, suggesting folding or at least tilting before deposition of the later beds.

The radiocarbon dating indicates an age greater than 32,000 years for some of the lignites in Cutting A (Rubin, M, and Alexander, C, 1958, W444, p. 1483). This specimen was submitted on the mistaken idea that the conglomerates in this cutting were morainal and associated with the Malanna glaciation. A considerable age for most of the gravels is indicated also by the extent of weathering of the dolerite boulders. The deposits are clearly post-dolerite, the dolerite probably being Lower Jurassic. Some of the material from the lignitic beds in Cutting E was submitted to Dr. I. Cookson for palynological analysis. Seeds and seed cases on cones of *Banksia* cf. *marginata* were reported from the sample, so that a Cainozoic age seems likely and possibly an Upper Cainozoic age in view of the close resemblance of the seed cases to forms still living in the area. Final dating must await detailed palynological work but the beds might best be considered Upper Cainozoic and this would be in accord with Johnston's record (1892, pp. 12-13) of *Acacia* from this area.

The rocks in the cuttings thus provide no evidence of a glacial origin and there is no physiographic evidence for glaciation in the area. On these grounds alone the hypothesis of the existence of a Malanna Phase of the Pleistocene Glaciation in the Malanna area, must be considered invalid. Before providing an alternative explanation for the observed facts, a final point in David's argument must be dealt with, that of the "brecciated pavements". To put the features so interpreted by David in their correct perspective the structure of the area must be considered.

STRUCTURAL GEOLOGY

The structure of the Lower and Middle Palaeozoic rocks to the east has been figured and briefly described by Gill and Banks (1950), is not relevant to the advancement of the argument, and will not be considered further. The Permian rocks near Firewood Siding are faulted against the older rocks. North of Firewood Siding is a fault, here called the Firewood Siding Fault, trending west-north-west and downthrowing to the south-south-west. This continues to about a mile east of Firewood Siding where a fault, the Eden Fault, trending north-north-east and downthrowing west, becomes the main structure. In general, the Permian rocks in the downthrown block dip to the south-west at angles varying from a couple of degrees to 50°, the latter occurring in Cutting M, that nearest the Tertiary beds, and suggesting a fault downthrowing to the south-west. The dips are all shown on the map (fig. 2).

In Cutting S there is a normal fault trending 330° (all bearings related to true north) and causing a distinct drag dip showing west side up. Joints trending 10° and 325° are common in this cutting. On some of the 325° joints are slickensides dipping west at a low angle and indicating west block north movement. Slickensides also occur on some of the bedding planes and show that the top moved west or north-west over the bottom.

Cutting R is that containing the rocks figured by David (1926, p. 102). At the eastern end of the cut the beds dip 115° at 30° and show joints trending 350° and dipping steeply west. Near the western end is a fault striking 340° and dipping west at about 45° and this is associated with much brecciation. In addition to these main faults, there are many minor normal faults dipping steeply west with a few normal faults dipping east and several minor thrusts dipping west. The beds affected are a formation of quartz sandstones and thinly-interbedded fine quartz sandstone and carbonaceous siltstones. The section figured by David is in the fine sandstone-siltstone alternation and

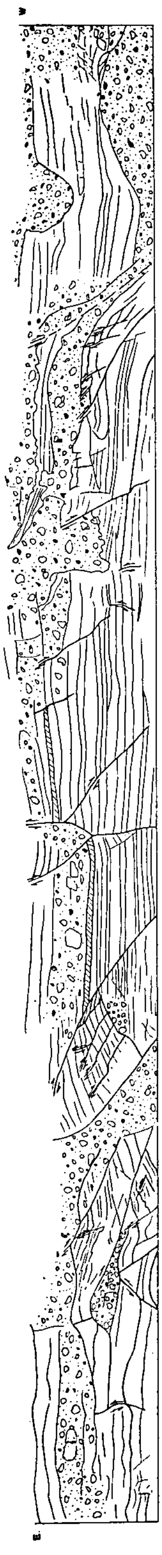


FIGURE 4 Diagrammatic Section of Cutting 'R', Malanna

SCALE 5 FEET

these beds are consistently the ones showing the most brecciation and minor faulting. It is notable that in the main body of the cutting a bed of thickly-bedded quartz sandstone at the top of the cut is not affected by brecciation nearly as much as the underlying alternation of fine sandstone and siltstone. The structure along this section is shown as Figure 4.

Near the eastern end of Cutting Q is a normal, westerly-dipping fault striking 325°. In the body of the cutting the beds are horizontal. They are strongly jointed in places, the main joints trending north and showing horizontal slickensides indicating west side north movement. At the western end is a normal fault downthrowing to the east.

In Cutting P is a normal fault near the western end dipping 190° at 74°. In Cutting O the beds are almost horizontal, although in places they dip west and form a small monocline. They are disturbed by a small thrust dipping west and by joints mainly trending 340° but with some at 10°. The dip is west in Cutting N and there are minor faults. Joints are common, striking 120° and there are some parallel to the cutting which show horizontal slickensides. The Permian sandstone near the end of Cutting M dip 230° at 50° and this steep dip probably indicates a fault downthrowing south-west in the vicinity. Tertiary conglomerates in the next cutting west (L) appear to be horizontal. This may show that the fault is pre-conglomerate, but the cuttings are quite a few yards apart, so that the drag dip might lie due east of Cutting L.

The Permian rocks then show numerous normal faults, mainly trending north-westerly and forming small horsts and graben. With these are associated minor west-dipping thrust faults. The normal faults trend 330°, 340°, 325°, 10° and 280°. Joints trending 300°, 325°, 340°, 0° 10° and north-easterly occur. On the 325° set and the 0° set there is evidence of dextral movement and there is horizontal movement also on the north-easterly set. The faults are consistent with tension from S.W.-N.E. and some of the joints fit this pattern also. However, some joints do not seem to be related to this tension and a more detailed analysis is required. One case of bedding plane slip with movement down to the west or north-west was noted.

The major structures are quite inconsistent with faulting produced by an ice sheet moving from east to west. What thrusts are present dip west. The only evidence for ice thrust is the bedding plane slip but this could also occur with normal faulting of dipping beds.. Thus structures in the Permian rocks at Malanna used by David to support his hypothesis of glaciation in the area are inconsistent with this but consistent with normal faulting.

The Tertiary beds also show variations in the dip and some faulting (see fig. 3*b*). In the northern cuttings they are horizontal or nearly so. In Cutting E they dip 230° at 26° and in Cutting D they dip 85° at 28°, so that a syncline may be inferred, the axis trending roughly 340°, between these cuttings. In Cutting A the beds at the north end dip 50° at 40° and those in the south end dip 240° at 6°. An anticline, trending about 325°, would appear to be present. In Cutting F there is a fault with small displacement and in Cutting A two normal faults forming a graben. The northern one dips 260° at 45° and the southern one 50° at

50°. This graben would have a trend of about 335° and this is close to the main fault direction in the Permian rocks. Approximate coincidence of the fold axes with the fault directions suggests a genetic connection.

SOME ASPECTS OF THE GEOLOGICAL HISTORY

The Palaeozoic history of the Malanna area has been dealt with elsewhere (Gill and Banks, 1950, and Banks and Ahmad, ms). It is relevant to the present discussion only that the Lower and Middle Palaeozoic sediments were folded into plunging folds and then overlain unconformably by more or less flat-lying Permian sediments. Dolerite intrusions occurred in the Jurassic. At some later time the Firewood Siding and Eden Faults developed. The Henty Surface cuts across these faults and thus is later. This surface cuts across the Lower and Middle Palaeozoic rocks despite their differential resistance to erosion. It is, therefore, an erosional surface. Thin layers of gravel occur on it in places but there is no evidence that it is a stripped surface. It is certainly not a stripped pre-Permian surface as the Henty Surface extends inland to the foot of the West Coast Range where it has a height of 1,100 feet approximately. This range is probably a monadnock range as postulated by Bradley (1954, p. 195). The top of this range is probably part of the stripped pre-Permian surface (Bradley, 1954, p. 195), as shown by the Permian at Mount Sedgwick (Edwards, 1941), Mount Read and Mount Dundas, where the base of the Permian is at over 3,000 feet. The Henty Surface is now dissected by stream valleys up to 700 feet deep but some of the original surface remains, so that it is not likely to be as old as Early Tertiary. The surface was deeply dissected by rivers prior to the formation downstream from the Henty River road bridge of the terminal moraines. These moraines are dissected little except for the gorge cut through them by the Henty River and are thus probably not very old. Both the glacier responsible for these moraines and the glacier which occupied the Linda Valley are distributaries of the minor ice cap which occupied the West Coast Range between Mount Sedgwick and Mount Tyndall. The advance of the glacier occupying the Linda Valley has been dated as about 26,000 years, i.e., about equivalent to the beginning of the Wisconsin Glaciation, and the moraines below the Henty River road bridge might well be almost contemporaneous. They could probably safely be considered as Upper Pleistocene. Thus, the Henty Surface was formed well before the Upper Pleistocene.

The relationship of the sediments in the railway cuttings to the development of the Henty Surface cannot be established on evidence so far available in this area. They may have been deposited in lowlands in a pre-Henty surface of considerable relief. They may have been formed in a graben in this landscape delineated by the Firewood Siding and Eden Faults. The fault postulated between Cuttings L and M probably preceded the deposition of the gravels in Cutting L because of their horizontal disposition. At a later stage the Henty Surface would have been eroded in the Lower and Middle Palaeozoic, Permian and Cainozoic sediments. On the other hand the Cainozoic sediments may have been deposited as the Henty Surface was developing, streams stripping material off the higher country and depositing in the valleys until a surface, partly erosional and partly depositional, was formed. Yet again, the sediments may have resulted from uplift of the Henty Surface along a fault line between Cuttings L and M with formation of alluvial fans and fluviatile plains against the steep fault scarp. The sediments may have gradually filled up the fault lowland until they reached a profile of equilibrium related to the Firewood Siding Surface. No evidence is yet available to allow a choice between these alternatives.

The surface from which the Cainozoic sediments were derived must have had a considerable slope, at least in places, to account for the large particle size in the gravels. Boulders up to five feet in diameter in bedded deposits with a sandy matrix imply a considerable velocity and volume of water and thus a steep gradient. Variations in the competence of the depositional currents are shown by the occurrence of interbedded gravels, sands and clays. There is evidence of a systematic variation in current competence in the succession—gravel, sand, clay (with or without lignite)—which is developed completely or incompletely eight times in the sediments of Cutting E and three times each in Cutting D and Cutting A. The recurrent increase in competence represented by gravels, in many places associated with local disconformities, may be due to recurrent increases in rainfall following periods of lower rainfall, or to recurrent uplift due to faulting or lowering of base level. On several occasion peaty swamps were present. The cross-bedding in the sands suggests two sources, one to the north or north-east of Cutting L and the other somewhere between Cuttings E and F. Thus cross-bedding, dipping in a generally southerly or south-westerly direction occurs in most cuttings but cross-bedding dipping north or north-west occurs in Cuttings F, I and K. The presence of dolerite boulders in all cuttings suggests a northerly derivation, the dolerite mass near Firewood Siding probably being the source. The Owen Conglomerate boulders in the older deposits and superficial gravels in and south of Cutting E suggest a partial derivation of sediments in these cuttings from the east, the nearest Owen Conglomerate being about a mile and three quarters south-east of Firewood Siding. Some of these sediments are older than 32,000 years and some of them are older than the Firewood Siding Surface. In all cases it is probable that they are older than the last phase of the Pleistocene glaciation. Subsequent to deposition of the sediments in Cuttings A to E folding and faulting occurred. The trends of the folds and faults are almost parallel and this suggests genetic connection. They may well be due to slumping on a clay bed down a slope trending about 340° and dipping south-west. This roughly parallels many of the faults in the Permian rocks, and the slope may have been a fault scarp.

At some time after the development of the Henty Surface it was uplifted. Partial erosion of this surface produced the Firewood Siding Surface, cut in Lower Palaeozoic, Permian and Cainozoic sediments (at least those in Cutting L). The Henty River appears to have been a meander in this surface and after uplift was entrenched in it. At the time of development of the surface the Henty River locally had a height of about 400 feet relative to present sea level and must have been higher further upstream. As the terminal moraines on the Henty River have a height of only about 250 feet above sea-level at their downstream termination and there is no evidence of displacement or tilting of the Henty Surface between Malanna and the Henty River road bridge, the moraines must be later than the development of the Firewood Siding Surface. Thus this surface is pre-Upper Pleistocene. The surface falls from about 400 feet at the Eden Fault to 350 feet at Cutting L, a distance of about two miles, so that there is a fall of about 25 feet per mile. The base level controlling this surface is not known. "Beach terraces" at a level of about 400 feet above present sea-level are recorded by Twidale (1957, p. 12) from just north of the Pieman River, about sixteen miles north of the Malanna area, where they are incised into a higher plateau. No evidence is quoted for a marine origin for these "beach terraces", nor near Malanna are any marine deposits known at this level. It is not, of course, clear that the "beach terraces" and the Firewood Siding Surface are in any way related but there is some parallel in the relationship of the two features to a higher surface and sea-level. The Firewood Siding Surface postdates both the sediments in the railway cuttings and the Henty Surface. Since development of the Firewood Siding Surface there has been rejuvenation and the knick-point on the Badger River has moved upstream about three quarters of a mile.

For fuller and more accurate reconstruction of the Cainozoic history and palaeogeographies, detailed sedimentation studies will have to be made and some method of correlation evolved which is applicable to the terrestrial sediments. This may well involve comparison of quantitative pollen analyses of the lignites. In addition, more information on rock distribution and detailed study of contour maps of this and neighbouring areas will be needed.

SUMMARY AND CONCLUSIONS

After development of the Firewood Siding and Eden Faults in a terrain of Palaeozoic sediments and dolerite, erosion produced the Henty Surface. Before, during, or after formation of this surface, a thickness of at least a few hundred feet of terrestrial gravels, sands, silts, and lignites was deposited. The grain size of some of the gravels indicates considerable gradient for the transporting streams. The succession, gravels, sand, silt or clay, is repeated completely or incompletely at least eight times.

Uplift of the Henty Surface was followed by erosion which finally produced the Firewood Siding Surface. This latter surface developed after deposition of some of the sediments. Further uplift resulted in erosion of the Firewood Siding Surface. After this uplift glaciation affected the West Coast Range and the Henty River valley as far downstream as the road bridge about eight miles east of the Malanna area at a height of about 250 feet above sea-level. This glaciation was probably equivalent to the Wisconsin in the Northern Hemisphere. The uplifted Henty and Firewood Siding Surfaces are locally being dissected by streams which, at least in the Lower and Middle Palaeozoic rocks, are strongly structurally controlled.

In the Malanna area there is no evidence of Pleistocene glaciation, whether by ice-sheet or otherwise, and the physiographic, sedimentational and structural evidence advanced by David (1926) in support of glaciation in this area was misinterpreted. More detailed studies indicate that all the facts known about the area suggest a Cainozoic history involving faulting, deposition of terrestrial sediments by streams, or in lakes and swamps and erosion by streams. It is concluded, therefore, that there is no longer any justification for retaining the term "Malanna Phase" for a Pleistocene glacial phase based on this area. Use of the term should be discontinued.

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LOCALITY INDEX

	Lat.	Long.
	41° 50′	145° 30′
Badger River	41° 59′	145° 14′
Firewood Siding	41° 59′	145° 16′
Geologists' Creek	42° 00′	145° 16′
The Gooseneck	41° 52′	145° 33′
Henty River	42° 02′	145° 18′
Henty Siding	42° 02′	145° 15′
Malanna	42° 01′	145° 13′
Mount Professor	41° 59′	145° 22′
Mount Read	41° 50′	145° 30′
Mount Sedgwick	42° 00′	145° 35′
Pieman River	41° 50′	144° 55′
West Coast Range	41° 44′	145° 33′
	42° 18′	145° 38′

Maxwell R. Banks

GLACIAL MAP OF TASMANIA

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BACKGROUND.

The traditional view of the Pleistocene glaciation of Tasmania is based upon the pioneer work of A. N. Lewis. Over a span of twenty-five years, Lewis conducted spare-time field work in a number of mountain areas, most of them difficult of access. All contained phenomena which in many cases have still to be adequately described, much less their full implications elucidated. Armed with an intimate knowledge of the Tasmanian mountains, but handicapped by a lack of first-hand knowledge of mountain glaciation, Lewis evolved his hypothesis of the multiple glaciation of the island in sixteen articles published between 1922 and 1945. In postulating multiple glaciation, he was influenced by the comments of Griffith Taylor on nivation levels at Mt. Field (Taylor, 1922) and by Edgeworth David who mistakenly recognized Pleistocene till and moraines near Malanna and terraced outwash aprons at Strahan (David, 1926). His final scheme consisted of three full glaciations of progressively decreasing severity: the Malanna (ice-sheet), Yolande (valley-glacier), and Margaret (cirque) glaciations. With some hesitation, he tentatively suggested a correlation with the Mindel, Riss, and Würm glaciations of Alpine Europe (Lewis, 1924) but subsequently abandoned it (Lewis, 1934). Lewis recognized the evidence of ice-sheet action in localities such as the Central Plateau, the effects of ice-modification in many river valleys, and the distinctive morphology of the high glacial cirques. His mature views appeared as a paper on "The Pleistocene Glaciation of Tasmania" published in 1945 and presented afresh by W. R. Browne in 1957.

Subsequently, field evidence accumulating from several widely-dispersed locations gave rise to doubts about Lewis' interpretations: some of it proved sufficiently critical to undermine his whole scheme. For example, a radiocarbon age of 26,480±800 years was yielded by a piece of wood in the Linda moraine to which Lewis had ascribed a Malanna age; the supposed tills in the type area of the Malanna glaciation were shown to be explicable in terms of fault-scarp breccias produced by late-Tertiary faulting in association with fluviatile, paludal and lacustrine conditions; the Malannan moraine on Mt. Wellington was found to be periglacial solifluction material; the glaciation of the Central Plateau was shown to be contemporaneous with and a major contributing

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factor in the severe valley glaciation characteristic of the western margins of the Plateau; and it has been demonstrated that some valley-side cirques contributed ice to the larger valley glaciers in west-central Tasmania.

Such evidence has high-lighted certain weaknesses underlying Lewis' scheme, the most serious being the pre-occupation with erosional forms at the expense of the study of glacial deposits, and the failure to recognize that preglacial solifluction material may make up an important part of the drift deposits in some areas.

While the increasing volume of new work has served to indicate major deficiencies in Lewis' scheme of three distinct glacial stages, it has not yet succeeded in providing a coherent alternative. Accordingly, a growing proportion of the new evidence now being discovered is not being interpreted within a Tasmania-wide chronological framework due to the lack of a certain basis for correlation.

It was with this situation in mind that the Glacial Map of Tasmania was conceived in August 1963. It constitutes a factual statement of present knowledge of the glacial phenomena based on both published and unpublished accounts of field work, and on scrutiny of vertical aerial photographs. In compiling the map, the authors were heavily dependent on aerial photographs at scales of about four inches and two inches to the mile. The reasons for this dependence were two-fold. First, the island is mountainous, heavily forested and poorly served with roads, especially in the west. Access to formerly glacierized areas is easiest in the north and east and most difficult in the areas of cirque-and-valley glaciation in the west and south where temperate rainforest renders movement slow and scientific observation arduous. Second, a dearth of field scientists of all kinds, but particularly those with some background in glacial geology, has meant that field data accumulate slowly. Under these conditions, several years may elapse between the recognition of a problem from aerial photographs and its study in the field.

Much of the evidence shown in the Glacial Map can be explained in terms of a single glaciation of recent date. The relatively uniform morphology and weathering characteristics of moraines at widely different altitudes have been observed frequently. Similarly the presence of overridden cirques on the Central Plateau and elsewhere is explicable in terms of formation in the advancing hemicycle of a single glaciation: many discrete cirques inset into areas of ice-cap glaciation could have been formed in the retreating hemicycle of the same glaciation.

The Glacial Map indicates nothing specific about glacial stages, but the authors are aware of some of the anomalies it contains. The discovery of erratics beyond the limit of continuous drift (especially in such apparently unglaciated areas as the vicinity of Lake Lea and on Redan Hill in the upper Collingwood River valley) points increasingly towards a history of multiple glaciation. The first stratigraphic evidence suggesting more than one glacial stage has recently been reported by Paterson (1965). As work in new areas is added to the reappraisal of the evidence of earlier workers, the glacial history of Tasmania will probably take on a complexity equal to or surpassing that suggested by Lewis. A. N. Lewis may have been right about the multiplicity of glaciation in Tasmania, albeit for the wrong reasons.

The Glacial Map of Tasmania is intended not only as a summary of present knowledge of the glacial features of Tasmania, but as a basis for additional data as they become available. It is hoped that it will serve further to stimulate interest in the Pleisocene glaciation of the island.

GENERAL CARTOGRAPHIC CONSIDERATIONS.

The Glacial Map of Tasmania differs from previous glacial maps such as those of North America, Canada, Quebec Province, and the United States east of the Rocky Mountains in a number of important respects arising mainly from the paucity of field data, the nature of the glaciation, and the small size of the island.

The lack of field evidence can be gauged from the fact that little is known about Pleistocene marine levels, sub-drift relief, the extent of the glacial lakes in which the varved sediments were deposited, the maximum extent of ice during the Pleistocene, and the number of glacial stages.

The existing glacial maps of parts of North America and Europe are concerned largely with continental ice-sheet glaciation. While ice-caps developed in some areas of Tasmania, notably the western Central Plateau, the Cradle Mountain area, and the Tyndall Range, many areas experienced cirque-and-valley glaciation only. Thus, in compiling the map, the recognition of individual cirques, glacially abraded valley steps the alignment of moraine ridges, and local ice limits was a matter of first importance. This emphasis tended to give way in the ice-cap areas to a concern with ice-eroded surfaces, overridden cirques, overridden trough walls and plateau edges, and the location and size of moraine ridges.

A major difficulty derives from the fact that much of central and southern Tasmania is underlain by Jurassic dolerite, which dominates the constitution of the glacial drift. Due to the susceptibility of dolerite to chemical weathering, glacial striae are not preserved. When the till fines as well as the included boulders are both derived from and deposited upon dolerite bedrock, it becomes almost impossible to distinguish glacial drift from periglacial solifluction deposits. Moreover, till fabric analysis is of limited use due to the frequent occurrence of spheroidal dolerite boulders in the till. For these reasons, the demarcation of ice limits on parts of the Central Plateau is likely to remain a problem for some time to come. Moreover, in some areas such as Ben Lomond, much glacial till is thought to have been redistributed by periglacial activity; this material has not been mapped.

Despite the small scale of much of the morphological evidence of glaciation the major elements can be expressed adequately on a single map-sheet because of the small size of the island. The scale of 1 : 250,000 is small enough to express regional patterns of glaciation and yet large enough for many individual glacial landforms to be shown to scale.

Finally, reference should be made to some problems associated with the plotting of data from aerial photographs. The forest cover constituted the greatest single obstacle, especially in the west. The tree line lies above 4,000 feet in most of the glaciated country, with the result that large ice-erosional landforms are easily mapped, but most depositional and the smaller erosional forms are not readily apparent on the photographs. The precise nature of the problem varies from one area to another, but one case may be quoted in illustration. In the central west, heavily-wooded, steep slopes frequently alternate with lightly-timbered flats on valley sides developed in sub-horizontal sedimentary rocks. The resulting photo-pattern is not easy to distinguish from heavily-timbered moraine ridges and intervening plains with scattered trees. This difficulty was encountered in the Kia-Ora Creek valley (west of Cathedral Mountain) and on the southern slopes of Mt. Rufus where field work was necessary to resolve it.

A different kind of problem concerned the transfer of interpreted data from the photographic print to the base map. Over the central parts of the map this involved transference from photographs at about two inches to the mile to base maps at 1 : 63,360, followed by photo-reduction for tracing directly on to the 1 : 250,000 base. Despite the small reduction in scale involved in the first transfer, some difficulty was experienced with broad valleys of uniform forest cover lacking distinctive landmarks, e.g., the upper Canning River. Far greater difficulties accompanied the mapping of areas with no large-scale map coverage. In these cases, such as the glaciated mountains of the extreme south, detail had to be transferred by eye from photographs directly on to the base map at 1 : 250,000 scale.

THE GLACIAL CONVENTIONS.

Three kinds of glacial convention are used: areal, point and linear. The areal and linear symbols appear more or less to scale, with the exception of that for "moraine ridges" which had to be generalized to some extent in one or two areas, e.g., immediately south of Lake St. Clair. All the point symbols are standardized and in most cases constitute a generalization of conditions in the area covered. This is particularly true of the symbol denoting "ice-eroded surfaces, direction of movement known", such occurrences on the western Central Plateau, the Cradle Mountain area and the Labyrinth being too numerous for all to be plotted at the scale of the published map.

In the interests of clarity, colours have been used to distinguish categories of phenomena. Thus, with the exception of the convention for rock basins, all ice flow and ice erosion features are shown in black. Glacifluvial features appear in red, glacilacustrine in green, and ice depositional features in yellow ochre. Blue lines are employed for ice limits and ice divides.

In that many of the features in the more remote areas were plotted entirely from aerial photographs, the following qualifications of the terms used in the legend should be noted.

Cirques.

It is known that several of the cirques mapped are probably no more than nivation cirques (e.g., on Mt Charles and Mt. Hobhouse). They are included for two reasons. Certain differentiation from glacial cirques is virtually impossible on aerial photographs. Further, their disposition and aspect are consistent with and serve to emphasize the strongly asymmetrical distribution of the glacial cirques.

Overridden Cirques

Overridden cirques have been taken to be those which show no clear evidence of having been re-activated after the overriding phase. Numerous examples are known, the most frequent occurrences being on plateau surfaces, e.g., close to the Central Plateau ice-divide and east of Lake Will.

Rock Basins

In general, the minimum extent of the rock basin is shown. Most of these have been mapped on the basis of associated morphological evidence rather than lake soundings. As work proceeds, some revision is to be expected though it is considered unlikely that the broad pattern will be greatly modified.

Glacifluvial Features—Outwash Deposits

A great many river valleys in western Tasmania contain valley fills of probable outwash origin. The authors were unable to find a certain means of distinguishing between modified till fills, glacifluvial outwash fills and valley fills of non-glacial origin. Accordingly, only more or less contiguous deposits are shown, many of which have been verified in the field.

Hummocky Moraine

This term is used to denote any area of undulating, swell-and-swale moraine. It is not used in the sense applied by Hoppe to the Norrbotten district of Sweden, although it includes small areas of comparable deposits. Also included are areas of end moraine with markedly hummocky form, such as those north of Cradle Mountain.

Erratics Beyond the Limit of Continuous Drift

This symbol does not appear on the map in great numbers, a reflection of the paucity of the field data. Despite their small numbers, however, some of the erratics are important in that they occur well beyond other recorded evidence of glaciation. A notable example is provided by the large blocks of dolerite resting on Ordovician limestone near Lake Lea.

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MAP ERRATA.

A glacilacustrine deposit shown on top of Mt. Olympus (40.95 E. 82.3 N.) and an indefinite ice depositional feature shown just north of Back Peak (38.9 E. 87.5 N), are drafting errors.

D. E. WILKINSON, Government Printer, Tasmania.

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GLACIAL LANDFORMS IN TASMANIA

MAXWELL R. BANKS AND EDWARD DERBYSHIRE*

INTRODUCTION

Glacial erosional and depositional landforms are very well developed in Tasmania, where high mountain ranges in Precambrian and Ordovician quartzites and silicified conglomerate, and plateaux in Jurassic dolerite, supported cirque and valley glaciers and ice sheets during the Pleistocene Epoch. These landforms are well displayed to the observer on the ground and in the air.

For many students aerial photographs provide a relatively unfamiliar view of landforms. It is advisable, therefore, to use such photographs in association with topographical maps and if possible with ground or oblique aerial photographs. For this reason the listed vertical aerial photographs have been chosen from areas covered by topographical maps at scales of either 1:63,360 or 1:31,680. The appropriate maps are listed with each set. A selection of ground photographs is here included as Plates 1 to 8, and references are made in the appropriate places to others already published. The relationship of glacial landform to rock type can be seen by examination of geological maps in conjunction with the aerial and ground photographs. Appropriate available maps are listed with each set.

The glacial phenomena shown on the photographs cover the major categories used in the recent Glacial Map of Tasmania (Derbyshire et al. 1965) which shows all known glacial landforms in Tasmania. Plates 1 to 7 show landforms to be found on the stereoscopic aerial photographs listed.

THE GLACIATION OF TASMANIA

Glacial ice occupied over 2,000 square miles of western and central Tasmania at least once during the Pleistocene Epoch. Ice sheets developed on plateau surfaces, notably on the West Coast Range, the Cradle Mountain-Barn Bluff plateau and on the western part of the Central Plateau where a large ice sheet grew to a thickness of at least 300m (Figure 1). These ice sheets overspilled the plateau edges and ice escaped down the major valleys as outlet tongues. In some areas, the deep valleys were overtopped with ice so that at one stage, for example, the Central Plateau and the Cradle Mountain-Barn Bluff ice sheets coalesced, ice standing some 600m above the floors of the trunk valleys of the rivers Mersey and Forth. Elsewhere, outlet ice debouched on to high plains forming coalescing valley glaciers and piedmont glaciers as, for example, in the Lake St Clair district.

Beyond the areas of glaciation by plateau ice sheets, many smaller glaciers developed on the mountain ranges, particularly in the southern-western quadrant of the island. Many of these were localized areas of very severe erosion by valley ice, while others did not develop beyond cirque glacier stage.

Thus Tasmania has inherited a wealth of glacial landforms of both mountain and plateau type. The landforms typical of mountain glaciation are best seen in the ranges of the south-west. For example, in the Frankland Range, both isolated (discrete) and valley head ('trough end') cirques with well-developed *arêtes* are associated with cirque moraines and with glacifluvial outwash plains (see air photo set 24). In some ranges, glaciers became so thick that they completely filled the valley systems and overflowed locally by way of transfluence and diffluence cols to form reticular glacier systems, some cirques being modified by over-riding ice and rock surfaces becoming mammillated due to severe erosion of jointed bedrock (see air photo sets 24 and 26). Rock basins, common in discrete cirques even on the more weakly glaciated ranges, assume great dimensions in the heavily glaciated ranges lying marginal to the ice

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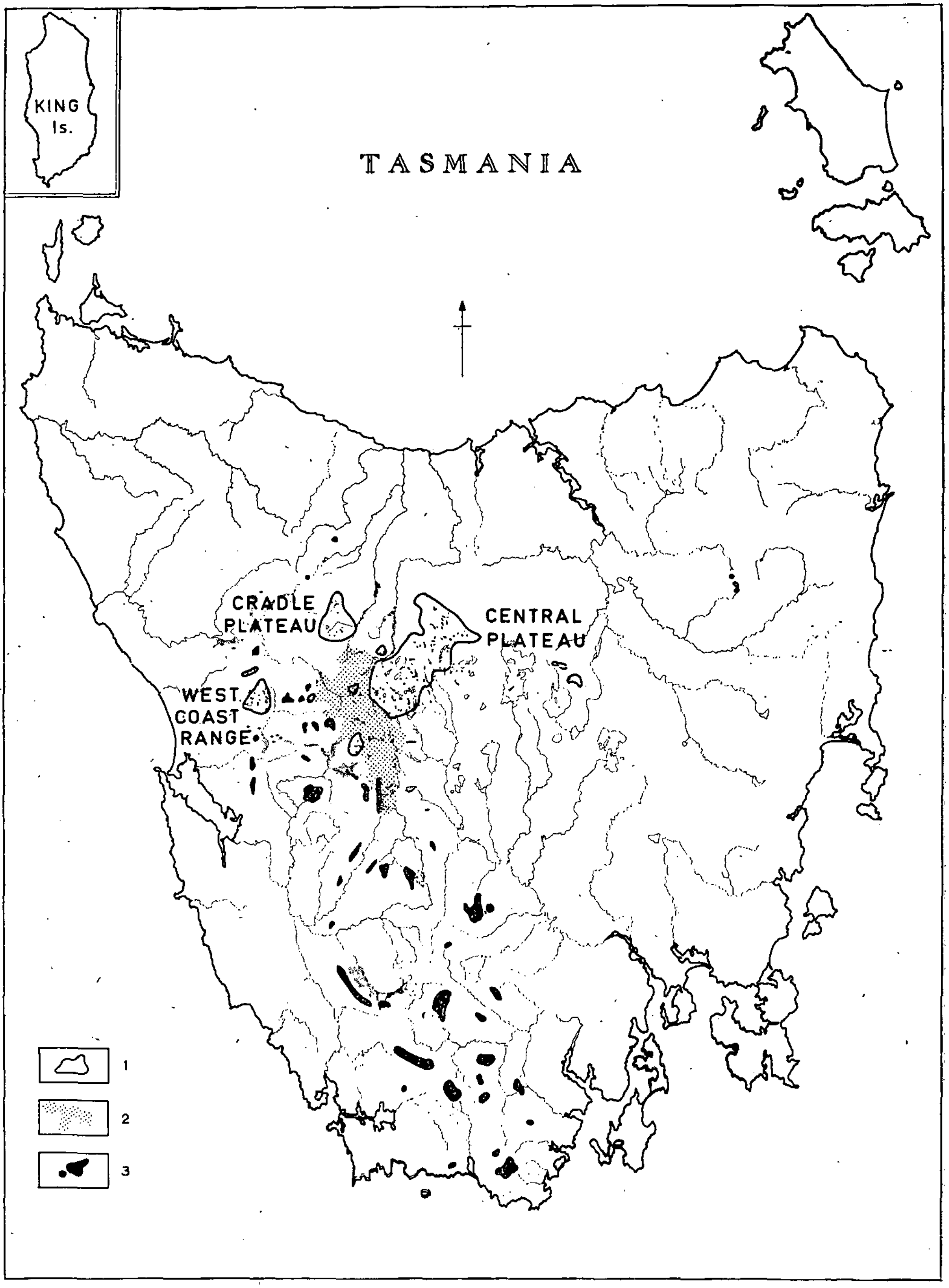


Figure 1. Location of areas in Tasmania affected by different types of Pleistocene glaciers:

1. major areas of ice-sheet glaciation,
2. major areas of reticular glacier systems and piedmont glaciers,
3. discrete areas of cirque and valley glaciation.

(Map (1:2,800,000) drawn in Dept of Geology, University of Tasmania: After Derbyshire 1966) sheet areas. Severe ice erosion on the eastern (leeward) side of the King William Range, for example, produced a series of deep, linear rock basin lakes in the valley heads, e.g. Lake Rufus (see air photo set 16). Outflowing ice from the western Central Plateau carved the 160m deep Lake St Clair and, as it retreated, laid down a great series of arcuate end moraine ridges in front of its 'expanded foot' piedmont ice lobe (see air photo sets 14 and 15). As the ice in all the valleys downwasted, a suite of morainal forms was deposited, including fluted drift moulded by active ice (air photo set 9) and hummocky moraine, sometimes with kettle holes, in areas where ice stagnated in place (air photo set 13).

The plateau areas which suffered severe glaciation by ice sheets are characterized by broad areas of ice-erosional forms including mammillated bedrock surfaces with *roches moutonnées,* abraded plateau margins, overridden cirques (air photo sets 3, 7 and 9) and rock basins carved along lines of weakness (best seen in the well-jointed dolerite of the western Central Plateau: air photo sets 17, 18, 19 and 20). Some unglaciated mountains (nunataks) stood above the ice sheets and reticular glacier systems (see air photo sets 6 and 11, respectively). Areas of drift moulded by strongly-moving ice sheets are marked by fluting, although true drumlins are rare (air photo set 2). Except for those moraine ridges laid down by the retreating outlet glaciers, the retreat stages of the plateau ice sheets are only rarely marked by end moraines, usually in certain favourable topographical situations (e.g. Clarence Lagoon: air photo set 23). However, there is abundant evidence of ice wastage in the form of hummocky moraine and kettled till plains (air photo sets 21 and 22).

PHOTOGRAPHS OF TYPICAL LANDFORMS AND NOTES THEREON

Plate 1

Lake Huntley, a small lake occupying a deep (450m) cirque, lies on the eastern (lee) side of a meridional range, the Tyndall Range, which lies between Queenstown and Rosebery in western Tasmania. The Ran is essentially an anticline of Lower Ord vician conglomerate and siliceous sandston and the major anticline is crossed by min anticlines and synclines and by minor hig angle reverse faults all of which trend nort west. One of the minor anticlines and a associated reverse fault are shown in th back wall of the cirque (called Huntle Cirque by E. J. Dunn in 1894). The Low Ordovician formation (Owen Conglome ate) includes thickly-bedded, white, siliceou conglomerates with silica cement which a very resistant to decomposition and disinte ration, and thinly-bedded pink quartz san stones which are less resistant. Most of th plucked back wall of the cirque is compose of conglomerate broken along prominen sub-vertical joints and the upper part of th back wall is composed of pink sandstone.

The eastern limb of the Tyndall Anticlin (i.e. the lee side of the range) is deepl eroded by ice and is now an almost con tinuous series of cirques of which Huntle Cirque is the northernmost major one. I some places along the range, ice accumu lated in the cirques sufficiently thickly t overflow saddles in the crest-line and flo as a thin sheet down the west side of th range. One such saddle is shown just le of centre along the crest-line.

Ice accumulating in Huntley Cirqu flowed east over a lip cut in conglomerat into the head of a northward-flowing valle glacier which spread out onto the flats nort of Lake Rolleston. That lake is at leas partially dammed up by the recessiona moraine loops of the glacier. Huntley Cirqu is perched about 150m above the floor o the main valley. The aerial photographs o set 1 include this cirque and other feature in this glacial system.

Plate 2

Eldon Peak, the prominent mountain in th central background, is capped by Jurassi dolerite and flanked by scree slopes derive from the jointed dolerite. The three mor rounded hills in the middle distance li approximately on the edge of the platea east of the Tyndall Range where it plunge

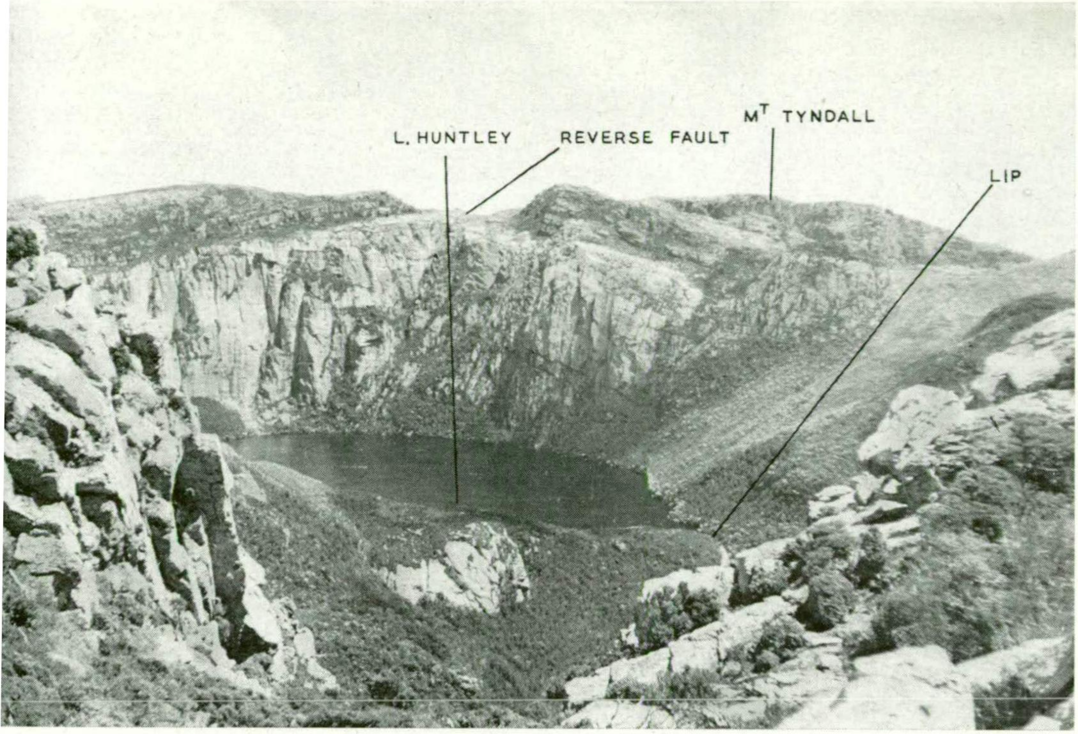


Plate 1. The Huntley Cirque, north end of Tyndall Range. (Photo by M. R. Banks)

eeply to the valley of the King River. The vo outer hills are composed of Precambrian ıartzites over which rode ice sheets of the ıinor ice cap which lay east of the Tyndall ange. The ice movement which produced e smooth, rounded surface of these hills as from left (north) to right and away om the observer. The low central hill is omposed of moraine and has been classied on the Glacial Map as 'hummocky oraine'. It has somewhat the shape in plan a drumlin but is an isolated feature and assification as a drumlin is therefore doubtl. Large erratics, mostly of Ordovician ıartzite and of Cambrian lavas, can be en on and close to this hill.

In the foreground is part of the iceoured plateau which lies east of the yndall Range, and several ponds or small kes occupying rock basins can be seen in is flat surface.

The photograph was taken from a low llock close to the shore of Lake Dora and covered by aerial photograph set 2.

Plate 3

At the southern end of the Tyndall Range is Mt Geikie (1,150m; left of centre) approximately on the axis of the Tyndall Anticline (see comments, Plate 1). The eastern slope of Mt Geikie is a sub-vertical plucked, back wall of a cirque, the western slope, facing the camera, a dip slope with scattered blocks, the result of periglacial activity, some of which is probably modern. Ice which accumulated in a series of cirques along the eastern side of the Tyndall Range coalesced to form a small icecap from which ice flowed east and south-east into the King River Valley and south into Lake Margaret Basin and over the Mt Sedgwick plateau into the Comstock Valley. Some of the ice in the Lake Margaret Basin flowed west over a low conglomerate lip and onto a flattish platform at 550m over which it flowed as a distributary valley glacier for about 2km.

An early stage in the retreat of the glacier left thin, low mounds, virtually mere lines

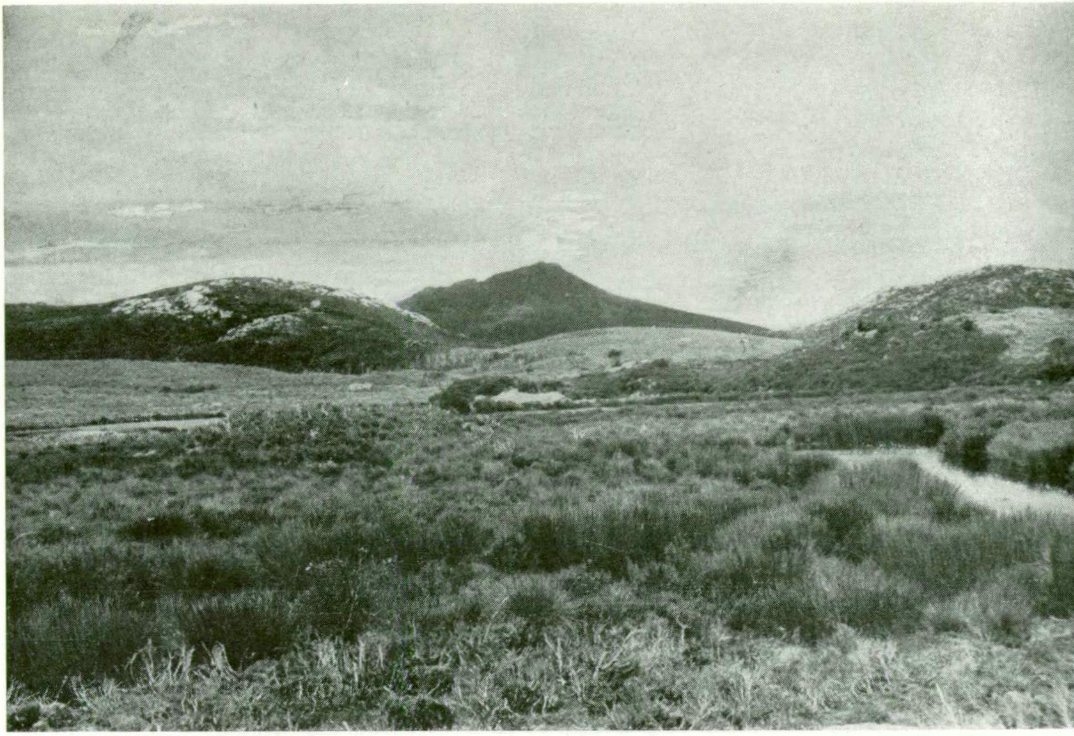


Plate 2. Glaciated surface near Lake Dora, with Eldon Peak in the background. (Photo by M. R. Bank

of erratics, as a series of recessional moraines north (centre left) of the main moraine loop. The most noticeable feature on the photograph, the long, sigmoidal ridge of till extending from the southern slopes of Mt Geikie to the photographer, is a thick (225m at its maximum height) moraine loop representing presumably a long still-stand in the history of the glacier. The moraine was referred to as the Hamilton Moraine by E. J. Dunn in 1894 and is the main evidence proposed by Lewis (1945) for the Margaret Phase of Pleistocene Glaciation. Some of the large erratics of Owen Conglomerate of which the moraine is composed can be seen on the button-grass-covered nearer slopes of the moraine. The part of the moraine visible is about half of the total moraine loop which extends from the north and south banks of Lake Margaret to the west. It is breached on the south-west by the Langdon River which has cut a precipitous gorge 170m deep in pos glacial time.

Retreat from the Hamilton Moraine wa rapid as no further recessional moraine were deposited though a thin outwash an ground moraine with minor eskers wa formed. Basin Lake was impounded betwee the outwash and the Hamilton Moraine.

The features shown in this photograph an others mentioned in this commentary a seen very well in set 3 of the annotated li of photographs.

Plate 4

Lake Margaret sits in a scoured rock basi and is impounded by a striated, polished li at its western end. The basin occupies synclinal structure crossing the main mer dional Tyndall Anticline and the island see in the photograph, which is of the easter end of the lake, consists of impure limesto

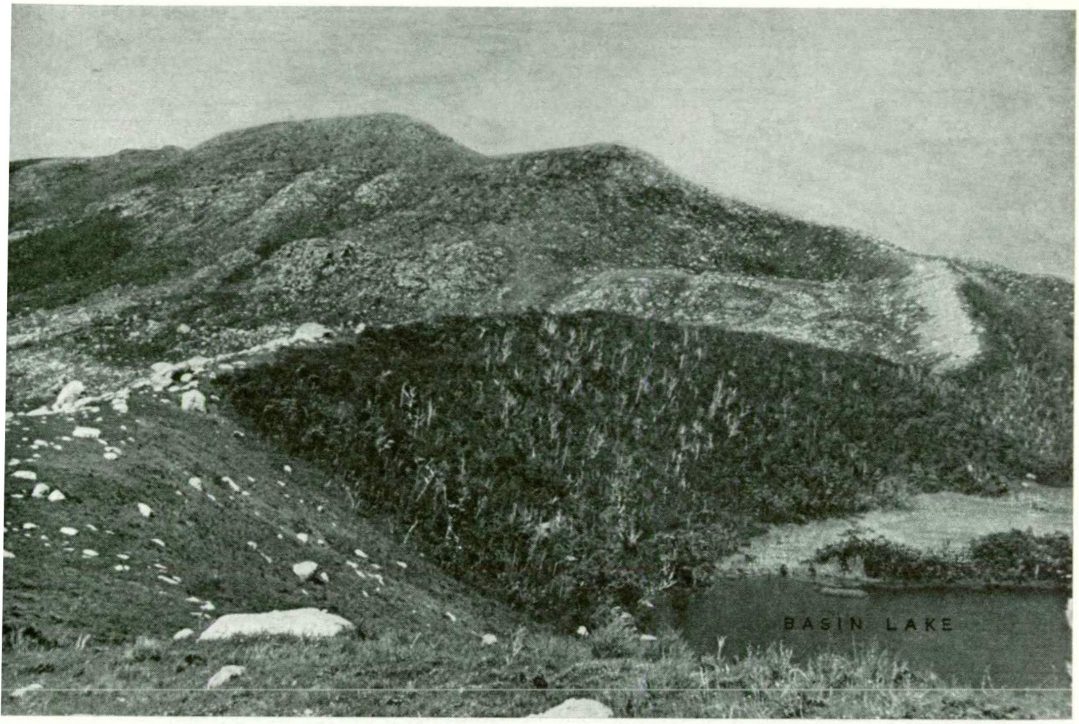


Plate 3. The Hamilton Moraine with Mt Geikie in the background. (Photo by M. R. Banks)

ansitional from the sandy upper member f the Owen Conglomerate into the Gordon imestone.

The eastern end of the lake is surrounded y erratic strewn, densely vegetated hill-opes passing up into striated and polished p slopes in Owen Conglomerate forming ammillated surfaces. The slopes lead up to a plateau surrounding Mt Sedgwick. his plateau is part of a sub-Permian sur-ce resurrected by Tertiary erosion and uaternary glaciation. The sub-Permian sur-ce was itself a glacially-eroded surface as ere are small *roches moutonnées* and riated pavements (indicating ice moving om the west) beneath a Permian (or Late arboniferous) tillite on the south side of It Sedgwick.

Ice from the minor ice cap east of the yndall Range moved south-east and south, ver and around Mt Sedgwick and some of is fell precipitously into the Comstock alley to the south.

These features can be seen well in set 3 of the annotated list of aerial photographs.

Plate 5

An aerial oblique photograph of the northern part of the Central Highlands (looking south). In the foreground is Dove Lake (left), and Crater Lake (right). Immediately beyond is Little Horn, Cradle Mountain, and further to the right Barn Bluff. Further into the background is Mt Emmett (left of centre) and in the distance is the Pelion Range with Mt Ossa just left of and behind the peak of Brown Mountain near the eastern end and Mt Pelion West at the western end.

The Pelion Range, Little Horn, Cradle Mountain, and Barn Bluff were nunataks of Jurassic dolerite projecting above the ice cap which covered much of the rest of the area shown during the Pleistocene. The dolerite intruded along the unconformity between Permian and older rocks. The sub-

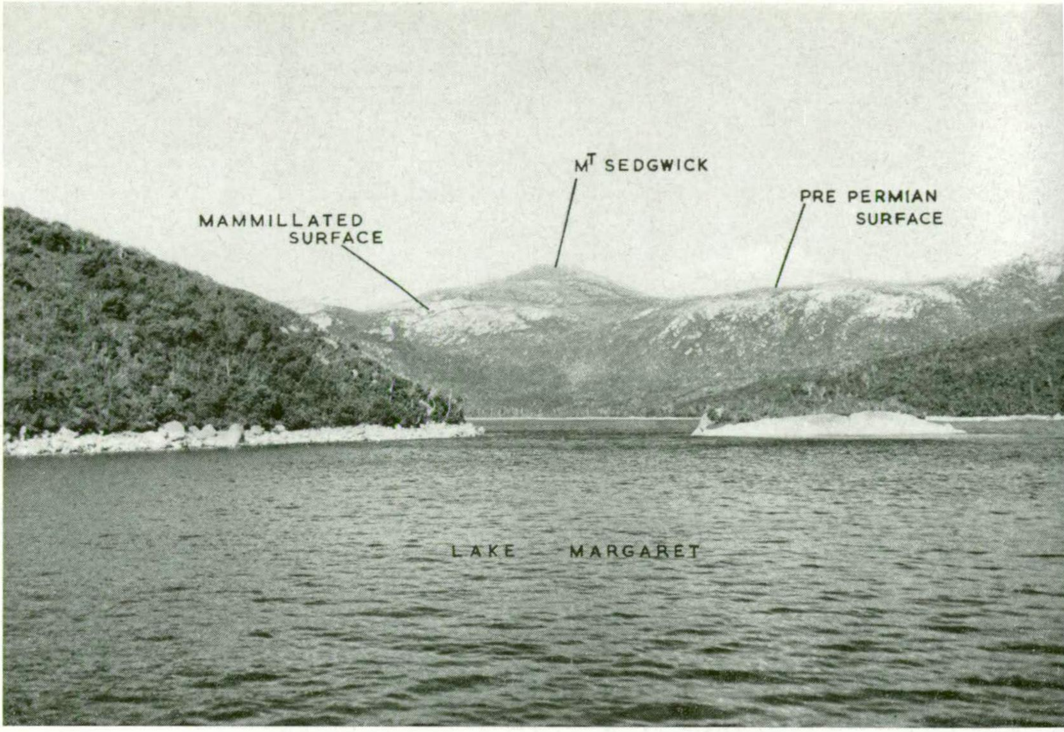


Plate 4. Lake Margaret with mammillated surface and Mt Sedgwick in the background. (Photo b
M. R. Banks)

Permian surface has been resurrected and forms plateaux east and west of Cradle Mountain underlain by Precambrian quartzites and the sites of accumulations of ice during the Pleistocene.

Ice from the ice cap overran cirques such as that just north of Cradle Mountain and that now occupied by Crater Lake. Ice overspilled the sides of the Crater Lake Cirque as well as flowing over the cirque threshhold at the extreme right of the photograph. Ice also overspilled the divides east and west of Dove Lake and the quartzite ridge north of Dove Lake. Some mammillated surfaces may be seen in the valleys and on the quartzite ridges between Dove Lake and the plane wing. Fine examples of striated and grooved surfaces may be seen by those who walk the track from Waldheim Chalet to Dove Lake, especially around the spurs of the ridge near the wing tip.

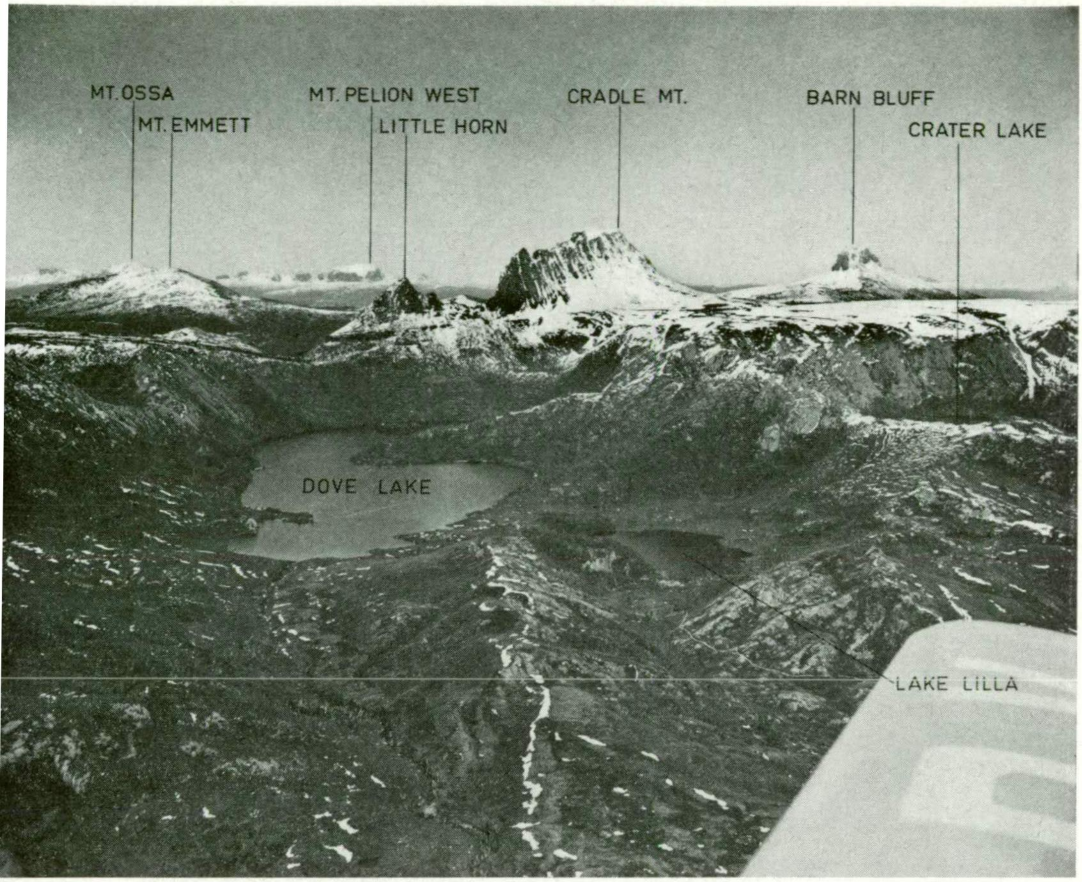
This area is covered by sets 6 and 7 of the annotated list of aerial photographs.

Plate 6

This photograph was taken by Dr A. H Spry looking south-west from an aeroplan flying approximately north-west at a lo altitude over Long Tarns (146°20′E 41°44′S) on the Central Plateau abou 32 km WNW of Great Lake.

The prominent group of lakes extendin from right of centre to the centre left margi of the photograph are part of a series know as Daisy Lakes (height of central lak 1,275m). These lakes are bounded on th east by a low spur running SSE from Merse Bluff and called Richea Ridge.

The group of mountains known as th Walls of Jerusalem extends across the photo graph in the middle distance, with M Jerusalem (1,500m) at the south, bordere to the north by the steep drop of the Eas Wall. A broad valley (including Zion Gate separates East Wall from a ridge with Zio Hill at its east (lower) end and The Templ



late 5. Glacial lakes and nunataks, Cradle Mountain area. (Photo by permission of Mercury Press, obart)

urther west. Behind these and seemingly urther north can be seen the prominent olerite columns of the West Wall with the Vailing Wall seen very obliquely at its outhern end. The ranges forming the horion include part of the Travellers Range southern horizon), mountains flanking the Aersey and Forth River Valleys and Mt Ossa (1,625m) at the northern end.

Visible bedrock is almost exclusively urassic dolerite, shown as somewhat mamillated outcrops (at bottom left) and in he more usual form of plateaux bounded y cliffs displaying abundant, well-developed ertical jointing as seen in the West Wall.

Ice movement was from left to right (i.e. rom SE to NW approx.) as may be seen in he orientation of the lakes which occupy ice-scoured rock basins, and in the form of Mt Jerusalem, with its gently sloping southerly and steep, plucked northern slopes. The major ice divide of the Central Plateau ice cap passes close to the south of Mt Jerusalem about the edge of the photograph and swings out of the picture to the left foreground. Hummocky moraine occupies much of the surface of Richea Ridge and can be seen in the right sub-central part of the photograph.

Somewhat similar topography is shown in set 20 of the aerial photographs. The area described lies on the Du Cane Sheet (Zone 7, Sheet 52) and 1:63,360 topographical and geological maps are available. It is covered in aerial photographs Central Plateau (1343) Run 2 T310 43-45. Jen-

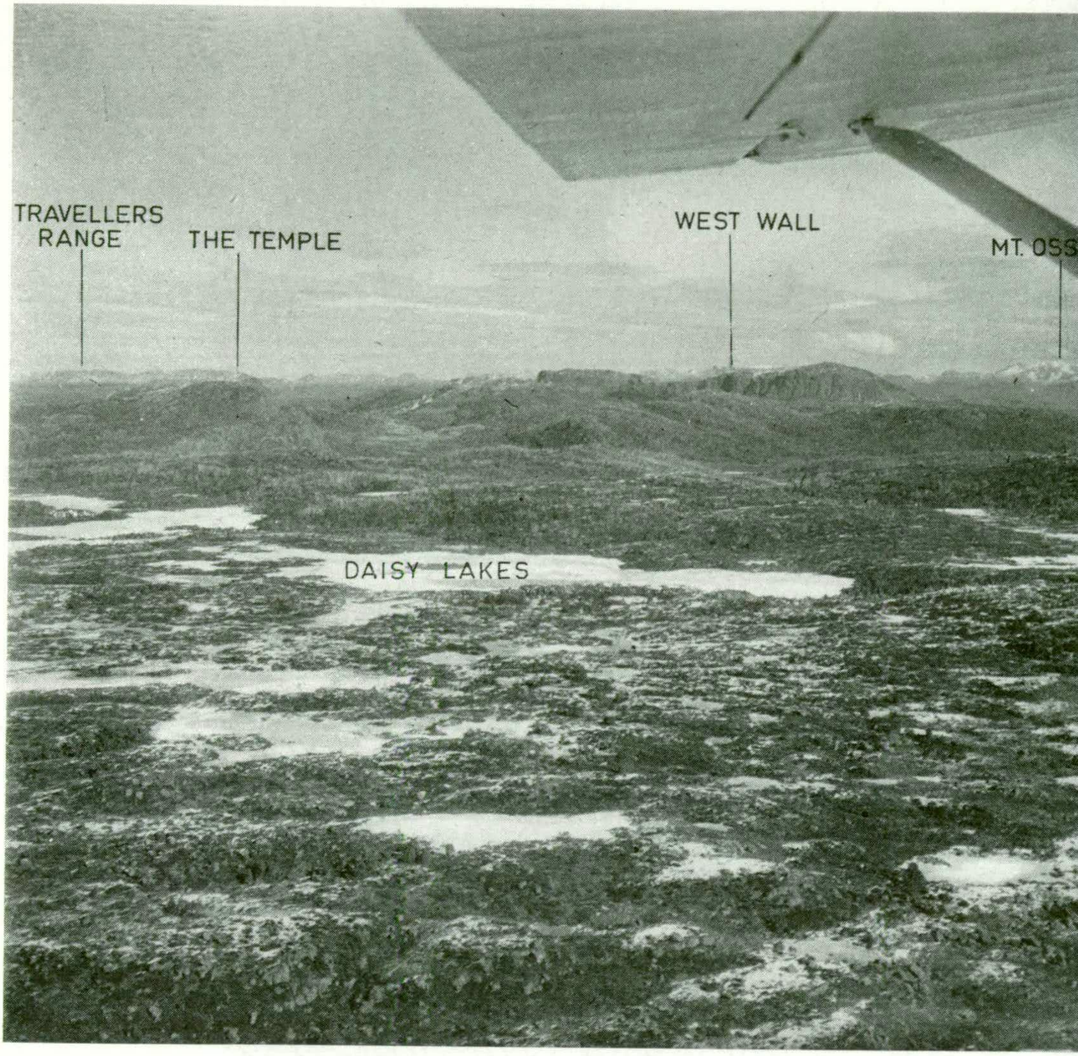


Plate 6. Glaciated surface of the Central Plateau with Central Highlands in the background. (Photo b A. H. Spry)

nings and Ahmad (1957) note the resemblance of the 'Lake Country' to Canada's Barren Grounds and to Finland and comment on its geographical uniqueness within Australia.

Plate 7

This photograph taken by Mr J. B. Thwaites from the jeep track up Mt Mawson in Mt Field National Park shows the valley of the Broad River to the north. Behind the trees in the left foreground (west) is Mt Bridges; in the valley are Lakes Webster (right o centre) and Seal (lower right), the latte separated by a low, north-west sloping ridge, from the valley of the Broad River beyond which is the higher ridge sloping down to the north-west from Mt Field Eas (out of the picture to the right). The whole area is underlain by Jurassic dolerite.

The main Broad River glacier flowed north-west between the low ridge east o Lake Seal and the ridge of Mt Field Eas and continued past the site of Lake Webster

ate 7. A glaciated valley with recessional moraines, the Broad River Valley. (Photo by J. B. Thwaites)

the end of the flat-floored section of the alley. A tributary valley glacier flowed from e large Lake Seal Cirque between Mt ridges and the photographer to join the ain trunk glacier just east of Mt Bridges. he low ridge separating Lake Seal from the road River Valley is a complex series of oraines lateral to the Broad River and the ake Seal Glacier, and on the hummocky rface of this ridge, small elongate tarns akes) are impounded. Lake Seal is a oraine-dammed lake occupying a deeply-coured rock basin. Lake Webster is a hallow lake on outwash and is moraine-ammed.

Downstream from Lake Webster the alley floor is a series of swampy, button-ass covered plains interspersed with low, ee-lined transverse ridges. The ridges are cessional moraines, the plains, which have occasional large erratics on them, either till plains, or more probably the floors of pro-glacial, moraine-dammed lakes.

The area shown in this photograph is covered in set 29 of the annotated list.

Plate 8

This photograph looking westwards from the track from Lake Esperance to Hartz Mountain in south-eastern Tasmania (468, 676) shows a *roche moutonnée* cut in Jurassic dolerite by a glacier moving left (south) to right. This photograph was taken by R. J. Ford.

The Hartz Mountains are an almost meridional range reaching 1,250m in height, cut into a dolerite sheet intruded into Triassic sedimentary rocks. The low westernmost ridge has been glaciated on its

Plate 8. Roche moutonnee in Jurassic dolerite, Hartz Mountains. (Photo by R. J. Ford)

eastern side where Lake Hartz lies as a moraine-dammed rock-basin lake upstream of a trough-end valley. The main ridge is flanked on its eastern side by a broad, complex bench, over many parts of which ice moved. The eastern side of the main ridge was the source of at least one valley glacier and of a number of cirque glaciers some of which coalesced on the bench to form very minor piedmonts. The ice of one such small piedmont glacier carved the *roche moutonnée* illustrated in the figure. The photograph was taken about 500m SSE of the southern tip of Lake Esperance, approximate grid reference 468.5, 678.4).

The characteristic form of a *roche moutonnée* with the gently sloping stoss side and abrupt lee-side termination shows clearly. The overall slope asymmetry is reflected on a smaller scale by the smooth, gently sloping southerly surfaces produced by abrasion and the very steeply sloping, somewhat jagged northerly surfaces resulting from plucking. Abrasion was facilitated b the sub-horizontal sheet jointing which con trols the profile of the northern half of th *roche moutonnée* and plucking was con trolled by the steeply-dipping to vertica joints so well-displayed at the northern end Such sheet jointing and steep jointing i common in the Tasmanian dolerite. Peri glacial activity has accentuated the shee jointing.

Most of the glaciated area of the Hart Mountains is included in the aerial photo graph pair South-west (1350) Run 6 T357 29-30 and on the Geevestor (1:31,680) Sheet 8211-I-S.

Annotated List of Vertical Aerial Photographs with Additional Reference Material

In each set, references are provided in the following sequence:

Aerial photographs. Name, (number), n number, sortie, photo numbers.
Topographic maps published by the :partment of Lands. Name (scale, Provi-)nal if applicable), Sheet number, G.R. 3.4, 576.8 (Locality).
Geological maps published by the :partment of Mines or available from other ıted sources. Name, (Geol., scale, author, te, and institution if not Dept. of Mines), R. 123.4, 567.8, (Locality).
Papers and monographs. Author and te. (See bibliography.)

:t 1

rque, plucked walls; minor cirques; U- aped valley, trough ends; transfluence cols; inor lateral moraine ridges (some diverting :eams); end moraine and recessional mor- ıe loops (in western part enclosing silted-) glacial lake); outwash plain, meltwater annel, rock basin and moraine-dammed kes. Lake Huntley occupies a classic :que (Plate 1).

Pieman (1347) 10, T324 16-18; Sophia :63,360, Provisional), Sheet 8014, G.R. 54.5, 836.0 (Lake Huntley). Dunn 1894.

:t 2

rques, over-ridden cirques, ice-abraded lley steps; transfluence cols; *roches outonnées*; mammillated surfaces; end- oraine ridges; ground moraine with erra- s; lineated drift; drumlin(?); rock-basin kes. (Set 1 adjoins.) (Plate 2.)

Pieman (1347) 10A, T316 12-15;)phia (1:63,360, Provisional), Sheet 8014, .R. 364.5, 836.0 (Lake Huntley). Dunn 394.

:t 3

attered erratics beyond major, multiple cessional moraine (Hamilton Moraine) eached by Langdon River; moraine- mmed lake (Basin Lake) on till plain; inor recessional moraine ridges and kames ı northern shoulder of Langdon River alley; minor recessional moraine ridges ·rth of Hamilton Moraine; lateral moraines ·rth of Lake Margaret; *roches moutonnées* near mouth of Lake Margaret; mammillated surfaces around Lake Margaret; steep plucked cirque walls east of Mt Geikie; nunatak (Mt Sedgwick); lineated drift; ground moraine (east of Lake Spicer); melt- water channel, end, recessional and lateral moraines of distributary glacier (Comstock Valley). (Plates 3, 4.) (Adjoins set 2.)

Pieman (1347) 11, T313 16-20; Sophia (1:63,360, Provisional), Sheet 8014, G.R. 362, 829.5 (Lake Margaret); Yolande, Mt Sedgwick (Geol., 1:63,360, Bradley 1954, Univ. Tasm.); Ahmad, Bartlett and Green 1959; Dunn 1894.

Set 4

End moraines of distributary glacier (Linda Valley); small rock-basin cirque 'hanging' above small glaciated valley on mountain side (Mt Owen); terminal moraine loops in several stages of dissection. (Davies 1965, pl. 1.) (Adjoins set 3.)

King-Franklin (1344) 2, T302 99-102; Franklin (1:63,360, Provisional), Sheet 8013; Mt Owen (Geol., 1:63,360, Bradley 1954, Univ. Tasm.), G.R. 363.5, 819.5 (Gormanston); Ahmad, Bartlett and Green 1959.

Set 5

Cirques, some occupied by rock-basin lakes; mammillated surfaces; transfluence and diffluence cols; ice-abraded valley steps; ground moraine, moraine ridges, glacifluvial deposits; meltwater channels.

King-Franklin (1344) 5, T302 112-114; 6, T301 83-85; Frenchmans Cap National Park Map (1:63,360); Frenchmans Cap area (Geol., 1:220,000, Spry 1963, Univ. of Tasm.), G.R. 384.7, 796 (Frenchmans Cap); Peterson 1966.

Set 6

Large nunatak (Cradle Mountain); plateau abraded by ice-sheet; over-ridden cirque containing Lake Wilks on valley step. (Plate 5.)

Pieman (1347) 5, T319 55-57; Sophia (1:63,360, Provisional); Cradle Mtn Re- serve (Geol., 1:126,720, Jennings 1958), G.R. 395.9, 868.3. (Lake Wilks); Benson 1917..

Set 7

Ice-abraded rock and lakes in rock basins; ice-overridden cirques; hummocky end moraine.

Pieman (1347) 4, T319 122-123; Sophia (1:63,360, Provisional); Cradle Mtn Reserve (Geol., 1:126,720, Jennings 1958), G.R. 395.5, 872.5 (hummocky end moraine, east of Waldheim Chalet).

Set 8

Glacially abraded valley steps in valley-head cirque (Mt Pelion West).

Pieman (1347) 8, T318 95-97; Sophia (1:63,360, Provisional); Cradle Mtn Reserve (Geol., 1:126,720, Jennings 1958), G.R. 398.0, 849.0 (Mt Pelion West).

Set 9

Valley-head cirques; *arêtes,* ice-scoured plateau surface and edges; ice-divide; recessional moraine ridges; fluted drift; moraine-dammed and rock-basin lakes.

Central Plateau (1343) 4, T309 35-40; Du Cane (1:63,360), Sheet 52; Du Cane (Geol., 1:63,360), G.R. 405.5, 840.0 (Massif Mountain); Derbyshire 1963.

Set 10

Valley-head cirque with rock basin lake and recessional moraines at foot of lake (Lake Marian).

Central Plateau (1343) 5, T309 27-28; Du Cane (1:63,360), Sheet 52; Du Cane (Geol., 1:63,360), G.R. 403.5, 830.5 (Lake Marian); Derbyshire 1963.

Set 11

Large nunatak (Mt Olympus) and glacial diffluence col cut across it. (Ground photo and oblique air photo in Derbyshire 1963.)

King-Franklin (1344) 1, T302 137-138; St Clair (1:31,680), Sheet 59A; St Clair (Geol., 1:63,360), G.R. 411.8, 821.8 (glacial diffluence col); Derbyshire 1963.

Set 12

Tandem cirques on Mt Olympus, both a rock basins; the northern cirque conta Lake Helen which is bounded by a large e moraine; the southern cirque is a sim rock basin with no end moraine; med moraine between cirques; craggy unglaciat plateau-like summit of Mt Olymp (Oblique air photo in Derbyshire 1964.)

King-Franklin (1344) 1, T302 136-13 St Clair (1:31,680), Sheet 59A; St Cl (Geol., 1:63,360), G.R. 409.8, 824.2 (La Helen).

Set 13

Hummocky moraine and small post-glacia infilled moraine-dammed lake (Upper P rarch Valley). (Ground photo in Derb shire 1963.)

King-Franklin (1344) 1, T302 135-13 St Clair (1:31,680), Sheet 59A; St Cl (Geol., 1:63,360), G.R. 405.4, 823 (hummocky moraine); Derbyshire 1963.

Set 14

Crescentric end moraines left by retreat large piedmont ('expanded foot') glacie over 80 distinct moraine ridges are show (best seen immediately NW and SW Bedlam Walls).

King-Franklin (1344) 3, T305 28-2 St Clair (1:31,680), Sheets 59A and 59 St Clair (Geol., 1:63,360), G.R. 417. 812.0. (Bedlam Walls); Derbyshire 1963

Set 15

Deep rock basin of major trunk glaci showing 'expanded foot' terminus; deepe lake and largest glacial lake in Australi well-developed lateral moraine on ridge W lake (Lake St Clair).

King-Franklin (1344) 2, T302 85-8 St Clair (1:31,680), Sheet 59A; St Cla (Geol., 1:63,360), G.R. 417.0, 815 (expanded foot of Lake St Clair); Derb shire 1963.

Set 16

Series of large glacial rock-basin lakes wi severe ice-abrasion of valley head; en

raines at lake foot; shows evidence of umulation of thick glaciers on leeward stern) (Lake Rufus) side of N-S moun- ı range (King William Range).
King-Franklin (1344) 6A, T307 24-25; ve (1:63,360, Provisional), G.R. 415.0, 3.0 (Lake Rufus).

17

ck basins on plateau scoured by ice- et. (Jennings and Ahmad 1957, Figs 4A,)
Central Plateau (1343) 3, T310 24-26; ı Cane (1:63,360), Sheet 52, G.R. 414.0, 3.0 (Chalice Lake).

t 18

ateau edge just south of Western Bluff; st-shattered 'windows' and ice 'spillover'. ennings and Ahmad 1957, Fig. 2B.)
Mersey (1346) 3, T304 16-18; Middle- x (1:63,360), Sheet 45; Middlesex (Geol., 63,360), G.R. 425.7, 875.1 (Western uff).

t 19

ıke (Explorer) with complicated shore ttern; *roches moutonnées* lining southern ore; moraines bordering north-western ore; most of lake is rock basin lake, outlet rough veneer of till.
Mersey (1346) 1, T306 42-44; Middle- x (1:63,360), Sheet 45; Middlesex (Geol., 63,360), G.R. 438.5, 863.5 (Lake plorer); Jennings and Ahmad 1957.

t 20

-scoured plateau surface; rock basin kes; ice-pushed ramparts around and ross lakes; ice-overspilled plateau edge; nsition east to lightly- or un-glaciated eas. (Near Plate 6.)
Central Plateau (1343) 1, T310 79-81; eat Lake (1:63,360), Sheet 53; Great ke (Geol., 1:63,360), G.R. 448.5, 854.5 econd Bar Lake); Jennings and Ahmad 57.

Set 21

Lakes formed by melting of ice blocks in moraine; just NW of Julian Lakes. (Jennings and Ahmad 1957, Fig. 4A.)
Central Plateau (1343) 1, T310 82-83; Du Cane (1:63,360), Sheet 52; Du Cane (Geol., 1:63,360), G.R. 440.0, 857.0 (north-western Julian Lakes).

Set 22

Sag and swell topography in ground moraine, ice-pushed ramparts; moraine dammed lakes; Double Lagoon shows a series of former ice-pushed ramparts at its western end and is divided by an ice-pushed rampart.
Central Plateau (1343) 3, T310 14-18; Great Lake (1:63,360), Sheet 53; Great Lake (Geol., 1:63,360), G.R. 450.0, 846.0 (Lake Augusta); Jennings and Ahmad 1957.

Set 23

Shallow valley dammed by large end moraine to form lake; also widespread till deposits in spreads and mounds (Clarence Lagoon). (Jennings and Ahmad 1957, Fig. 3.)
King-Franklin (1344) 2, T302 83-84; Nive (1:63,360, Provisional), Sheet 8013, G.R. 428.5, 818.5 (Clarence Lagoon).

Set 24

Valley-head cirques, *arêtes*; U-shaped valleys, ice-abraded valley steps; lateral, medial, recessional and end moraines; outwash plain; coalescence of valley glaciers to form minor piedmont; glacifluvial outwash plain, showing characteristic rills on its surface; outwash from cirque, valley and minor piedmont glaciers on the east side of the Frankland Range covers a large part of the centre of print 116; this outwash created Lake Pedder and maintains the outlet stream of this lake (Serpentine R.) on the east side of the valley (Davies 1965, pl. 2): similar features as well as mountain cirques, difflu-

ence cols and moraine dammed lakes may be seen in the photograph of the Mount Anne area near the other end of the set.
Gordon (1345) 9, T336 115-118; Wedge (1:63,360, Provisional), Sheet 8013, G.R. 407.5, 714.0 (Frankland Range), G.R. 415.0, 713.0 (Lake Pedder), G.R. 438.0, 710.0 (Lake Judd); Lewis 1924.

Set 25

End moraine and recessional moraine loops of glacier with upstream end in set 24; cirques with rock basin and moraine-dammed lakes and breached end moraines.
South-west (1350) 1, T360 20-21; Wedge (1:63,360, Provisional), Sheet 8013, G.R. 438.0, 710.0 (Lake Judd). Lewis 1924.

Set 26

Valley-head and isolated cirques; over-ridden cirques; *arêtes*; transfluence and diffluence cols; mammillated surfaces; ice-abraded valley steps, lateral moraine ridges, end and recessional moraine ridges; outwash plains.
South-west (1350) 4, T361 16-21; Dyelines available; G.R. 430.0, 685.0 (Arthur Ranges).

Set 27

Perched moraine-dammed lakes; cirques; *arêtes*; end, recessional and lateral moraine ridges; till mounds; lakes impounded by lateral moraine.
Gordon (1345) E. Key, T334 22-24; Wedge (1:63,360, Provisional), Sheet 8013, G.R. 425.0, 762.0 (Reeds Peak).

Set 28

Valley-head cirques; cirques; transfluence col; over-ridden cirque head wall (Lake Seal); U-shaped valleys; mammillated surfaces; nunataks; lateral moraine ridges; ground moraine; rock-basin lakes; moraine-dammed lakes; block streams (periglacial).
Tyenna (1593) 2, T466 219-222; Mt Field National Park Map (1:63,360), G.R. 450.0, 744.5 (Lake Belton); Lewis 1922.

Set 29

Névé fields; cirque with end and recessio moraine ridges impounding Lake Dob and Eagle Tarn; U-shaped valley, i abraded valley step; lateral and med moraine ridges, impounding Platypus T and other tarns; valley head cirque w overridden back walls; mammillated s faces; nunataks; block streams; tributary shaped valley; lake on till plain, small po in till plain (probably due to melting ice blocks in moraine); partially-filled shaped valley (of Broad River); tree-li recessional moraine ridges; erratics; termi till plain. (Plate 7.)
Tyenna (1593) 2A, T473 249-258; Field National Park (1:63,360), G. 451.8, 747.5 (Mt Bridges); Lewis 1922.

REFERENCE MATERIALS

Aerial photographs

The aerial photographs listed are all ava able from the Surveyor-General, Depa ment of Lands, Public Buildings, Dav Street, GPO Box 44A, Hobart, Tasman When ordering, sortie (and project numbe run number and photo number must quoted. All sets listed allow stereosco viewing of the features mentioned. The is by no means exhaustive but has be chosen to provide adequate cover of we displayed typical examples. The aer photographs are either 9 in. x 9 (1:35,000 scale approx.) or 9 in. x 7 (1:15,000 scale approx.). The costs of t photographs are set out below (as at d of publication).

	Government, semi-government, university	Priva
Per complete set	$35	$60

Prices for individual photos, photo pa or runs are available from the Surveyo General to whom inquiries on costs f multiple sets should be addressed.

Maps

Topographical maps are available from t Surveyor-General at a cost of 50 cents ea geological maps from the Director of ıes, GPO Box 124B, Hobart, 7001, Tasıia, also at a cost of 50 cents each. In a cases references are made to maps pubed by the Geology Department, Univer- of Tasmania, which are available from Professor of Geology, University of Tasıia, GPO Box 252C, Hobart, 7001, Tasıia, at a cost of 20 cents each.

[he Glacial Map of Tasmania with exıatory notes is available from the Secıry, Royal Society of Tasmania, GPO ‹ 1166M, Hobart, 7001, Tasmania, at a t of 75 cents.

ıjection slides

set of 20 black and white 35mm projection slides showing some glacial features in Tasmania is available from the Teaching Aids Centre, Education Department, Brisbane Street, Hobart, at a cost of $2.00 per set.

Other material

Additional background material, including ground photographs, is contained in the articles by Jennings and Ahmad 1957; Derbyshire 1963, 1964, 1966 and 1968; and Davies 1965.

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SOME ASPECTS OF THE SOUTH AUSTRALIAN URBAN SYSTEM*

Some Observations

CORRESPONDENCE

We congratulate Mr Smailes[1] on presenting the results of the first large-scale empirical investigation into central place system in a mainland Australian state; but it is important that the results be treated with care, since lack of complementary material ensures that these data will remain a standard example of Australian urban patterns for some time.

Mr Smailes attempted to answer the question: in a metropolitan nodal region, does the concept of a nested hierarchy of towns have any reality? The questions involved two notions (i) that in South Australia a hierarchy of towns exists, and (ii) that this hierarchy exhibits the nesting of trade areas proposed by Christaller.[2]

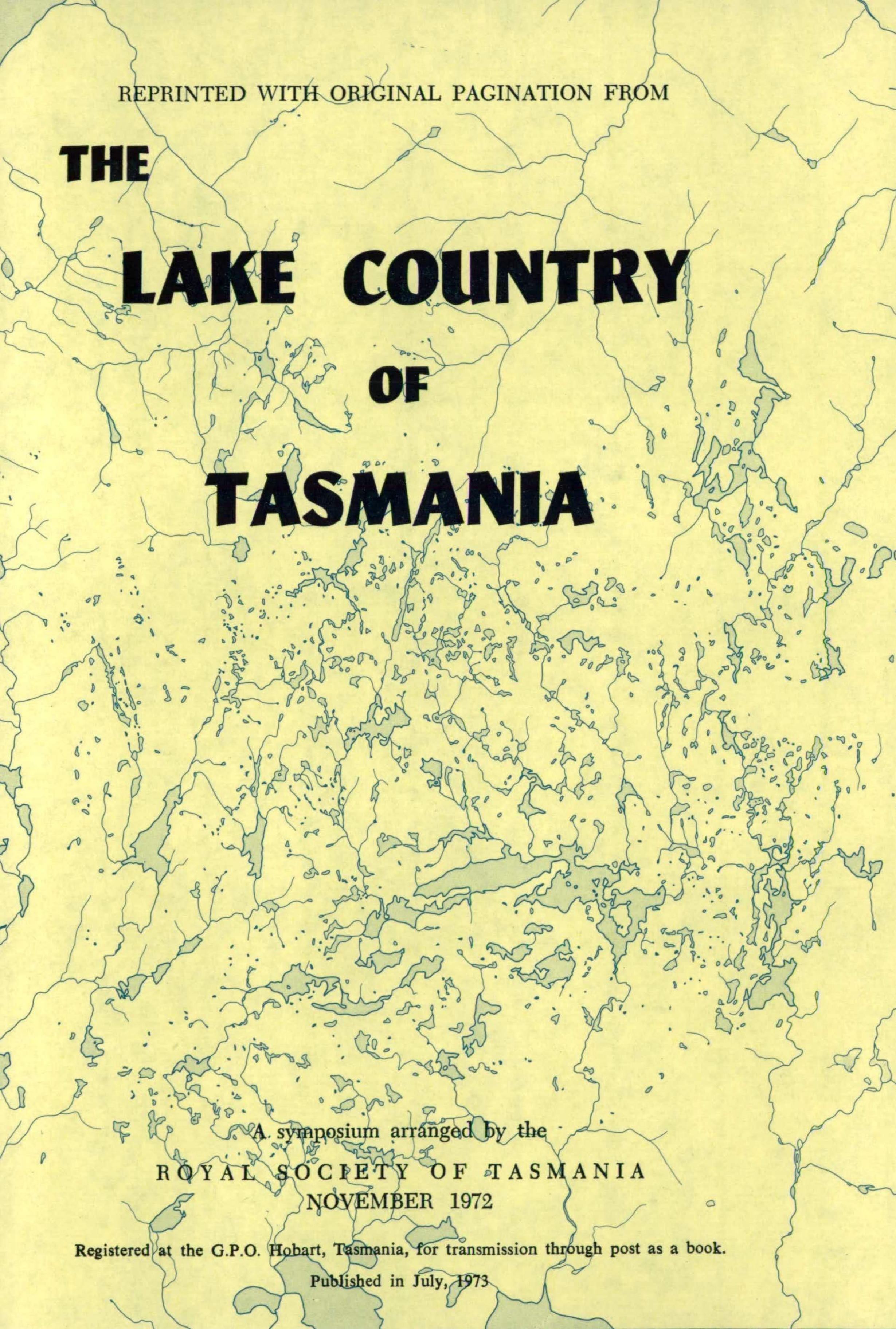
To test the first notion, Mr Smailes grouped the towns into six classes, on the basis of a graphical 'nearest neighbour' method. Unfortunately, the use of the term 'nearest neighbour' is misleading, for Mr Smailes has not used a set of techniques, based upon the Poisson probability function, to which significance tests can be applied. Instead, he has resorted to a graphical method which exhibits such a degree of subjectivity (e.g. in the choice of a three-stage grouping process and in the removal of the two upper classes from the process after the second stage) that the existence of the hierarchy has hardly been proved or disproved. (Indeed, it is doubtful whether one can ever *prove* the existence or non-existence of a hierarchy.) The problems of subjectivity arise in every grouping process, as Mr Smailes points out, but more powerful techniques minimize this factor and provide significance tests which distinguish the usefulness of various classifications.

Mr Smailes rejects the spectrum of grou ing techniques which have been develop by Lance and Williams[3] and others, par on the grounds of imperfect data sourc This rejection implies either that Mr Smai believed that the data were not in the fo which could be handled by these mo sophisticated techniques (which is not tru or that he felt the data so imperfect as to r warrant precise analysis. This latter implic tion throws the virtue of the whole exerc into doubt.

There arise equally important problems data when Mr Smailes investigates the tra areas in the state. Two different methods collecting data were employed. Mr Smai received questionnaire replies from 3 people (representing 502 towns) who list their normal and occasional movements obtain twenty-four goods and services; complemented this information with tel phone traffic data. The accuracy of the urb fields delimited with such limited data mu be questioned. More importantly, the tw data sources are not equally relevant Christaller's model. The questionnai results describe actual physical movemen which give rise to Christaller's symmetric distribution of towns when his assumptio are satisfied; but telephone traffic in t present day (unlike the time when Christall first employed the measure) represents substitute for actual physical movemen and, by reducing the friction of distanc could yield the market ordering propos by Rose.[4]

Rose suggested that many market tow in Australia trade directly with the sta metropolitan area rather than with highe order towns in the hierarchy. Mr Smail attempted to test this hypothesis by analy ing the destinations of telephone calls fro country towns. But these data are clear largely unrelated to the hypothesis:

* P. J. Smailes, *Aust. Geog.*, XI, 1969, pp. 29-51.



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GEOMORPHOLOGY

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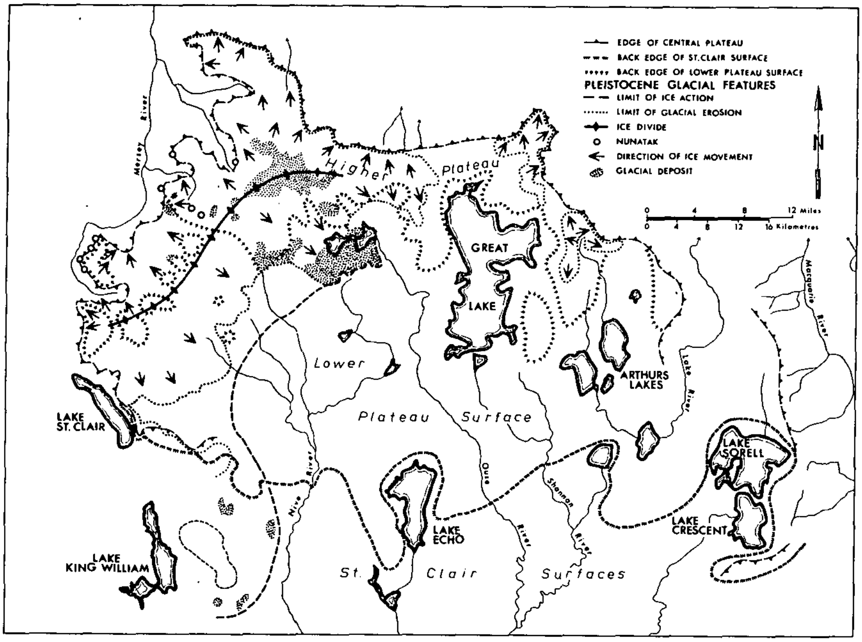
Surface Form

The Central Plateau rises from about 600m in the south and east to a maximum of about 1420m in the north and west. It consists of three main surfaces. The lowest or St. Clair Surface (Davies 1959 after Browne 1950) lies between 750 and 825m (see fig. 10), the middle or lower Plateau Surface between 900 and 1050m with many erosion residuals rising to heights of just over 1200m and the highest or Higher Plateau Surface rising from 1200m at its south-eastern limit to 1420m in the north-west. Lakes St. Clair, Echo, Sorell and Crescent lie on the St. Clair Surface close to its junction with the Lower Plateau Surface. The Lower Plateau Surface is separated from the Higher Plateau Surface by a sharp scarp, Great Pine Tier, in the south-west but the contact between the two surfaces near Great Lake is highly indented. On available evidence Great Pine Tier is probably a scarp which has retreated from the Great Pine Tier Fault (Macleod *et al.* 1961, Gulline 1963, and fig.7), but the faulting preceded the development of the Higher Plateau Surface as the level of the Surface extends across the scarp and appears as the tops of erosion residuals south-west of the fault (fig.10). It is interesting to note that at least four major lakes Augusta, Great Lake and Arthurs Lakes lie on the Lower Plateau Surface close to its junction with the Higher Plateau Surface thus repeating the relationship of lakes to the two lower surfaces. The relationships between the three surfaces suggest that they represent successive erosion levels separated in time by uplift phases as postulated by Davies (1959). It is noticeable that the lavas, including the Late Oligocene and Miocene lavas of the Great Lake area, occur only within the confines of, but form part of the two lower surfaces. The outpouring of lava must therefore have preceded the formation of these surfaces. However no such limit can yet be placed on the age of the Higher Plateau Surface.

Drainage

The plateau is drained mainly to the south by such tributaries of the Derwent as the Nive, Dee, Ouse and Shannon Rivers, but short tributaries of the Mersey, Meander and Macquarie Rivers drain the western, northern and north-eastern rims. The dominant stream trend on the Plateau is from north-west to south-east with



10. Geomorphological map of the Central Plateau.

a subsidiary trend from NNE to SSW over most of the Plateau but meridional south and west of Lake Echo. These directions, also well represented in the scarps bounding the Plateau and in Great Pine Tier, reflect the dominant joint and lineation directions in the dolerite and the directions of known faults. The joint and fault control result in the rectangular type of drainage pattern noted by Davies (1965, p.19).

Glaciation

Within the last 25,000 years, much of the western part of the Plateau was ice-covered (see Glacial Map, Derbyshire *et al.* 19 and subject to glacial erosion. The glacial divide extended from just east of the Travellers Range to just south-west of Julian Lal (see fig.10). Erosion extended to the rim of the Plateau to the north and west, east as far as Wild Dog Tier and south almost to Clarence Lagoon. Major glacial depositional features occur along the eastern flank of the ice sheet only in the area north-west of Double Lagoon and there are few along the southern flank except between Clarence Lagoon and Lake St. Clair. Minor ice caps occupi the south-westerly flank of Drys Bluff where the form of the ice-eroded surface suggests flow from the south-south west, and on the northern ridge of Bradys Lookout and Sandbanks Tier which seems tc have been quite separate from the other caps. The main evidence of ice erosion is in the form of ice-gouged and smoothed surfaces and roches moutonnees but striations are very uncommon. Glacially abraded valley steps occur in several places as do over-ridden cirques. The western edge of the plateau has also been over-ridden by ice. Depositional landforms resulting from ice action are mainly areas of hummocky moraine north and west of Lake Ada and extending almost to Blue Peaks, and area of ground moraine north and west of Double Lagoon and scattered minor moraine ridges. Glacial boulders are widespread and, as might be expected, are predominantly dolerite although erratics of basalt and hornfels are also known to occur locally. A basaltic boulder train extends from Lake Augusta to Lake Kay. The paucity of depositional landforms relative to the very extensive erosional ones may be partly due to the location of the ice divide close to the western margin of the plateau so that much of the ice and its moraine spilled over into the Mersey valley or into the Lake St. Clair basin, partly to the relatively minor amount of material eroded, as shown by the paucity of cases of breached divides and drainage diversions (Jennings and Ahmad 1957). The relatively minor remodelling of the landscape by the ice, especially that east of the divide, was noted by these authors who regarded it as a region of passive glaciation, produced by "very gradual slopes and slighter precipitation". The lack of end moraines has been attributed to gradual as opposed to spasmodic retreat of the margin of the glaciers (Davies 1969, p.178). The evidence suggests an ice cap sitting on the western and northern part of the Central Plateau about 50 km by 20 km and at least 240m thick in places with only occasional hills, such as the West Wall, Howells Bluff, top of Western Bluff, projecting through it as nunataks. Evidence recently collected near Great Lake and Monpeelyata Canal (Derbyshire 1968) suggest a cold period preceding the main glaciation, a cold period which may be an earlier phase of the last main cold stage or an earlier cold glacial stage. Two glacial stages are also suggested by evidence in the Forth Valley (Paterson 1965).

The lakes vary in character. Some occupy shallow depressions in the till plain and are simple whereas others in the same terrane are divided or almost divided by ice-pushed block ramparts (e.g. Double Lagoon). Some lakes (e.g. Clarence Lagoon) are impounded by end-moraine barrages. South of Lake Nameless are scattered small lakes which occupy depressions in till possibly due to collapse of ice blocks in the moraine. A few small lakes surrounded completely by solid rock are due to glacial over-deepening and the sides of these not infrequently parallel lines of structural weakness in the dolerite. Many, if not most of the larger lakes are of compound origin, partly occupying hollows due to over-deepening, partly dammed by moraine.

In addition to the numerous, rather small (less than 7.5 km long) lakes of the western part of the Plateau, are a few large lakes in the eastern and southern parts of the Plateau, e.g. Lake Augusta, Great Lake, Arthurs Lakes, Lake Sorell, Lake Crescent, Lake Echo and others. All of these lakes are wide and shallow and lie beyond the known limits of glaciation. As pointed out earlier, they all lie close to the upper limits of the St. Clair and Lower Plateau Surfaces. Their origin is not clear but it seems likely that they were formed by slight northward tilting of the erosion surfaces on which they lie (Davies 1965, p.22). This tilting is probably very recent, perhaps only a few thousand year ago, as the lakes although shallow have not been destroyed by filling with sediment. Dr. Colhoun (pers. comm.) remarks, howeve "that if tilting is recent old shore lines should be preserved, a least at one end. If tilting is a result of glacio-isostatic response which is dubious but possible then the north-west should be raised and the south-east lowered. If tilting is tectonic, th old shorelines should occur in places determined by the direction of tilting, i.e. if the argument advanced above is correct they should occur at the southern end." An emerged shoreline is prese near the pumping station at the western end of Arthurs Lake (as pointed out by K.D. Nicholls during the excursion) and reconnaiss study of aerial photographs suggest more deposition and perhaps emergence on the western sides of Lagoon of Islands, Woods Lake a Lakes Sorell and Crescent. This, if true, suggests the glacio-isostatic response mentioned above and implies that these lakes were already there as the ice began to melt.

Periglacial effects are particularly noticeable in the form of block streams that rim the Plateau on the eastern, northe and western sides but frost shattering resulting from Pleistocene and perhaps Holocene frost action is widespread, albeit less spectacular. The Pleistocene snow line has been estimated to have been at about 1200m in this area and the limit of periglacia activity must have been appreciably lower, perhaps about 600m as suggested by Nicolls (1965, p.28) and Davies (1968, p.12). Patterned ground occurs on moraine at about 900m in the south-western part of the Plateau (Jennings 1956). A block stream underlies th Chalet at Poatina at 260m above sea-level (McKellar 1957, Davies 1968).

POST-GLACIAL EVENTS

Several of the smaller lakes (e.g. Lagoon of Islands) are bordered on the eastern side by vegetated sand dunes suggesting a period dry enough to allow deflation, probably the Mid-Holocene

Arid Period from about 7000 to about 4000 years ago. Such dunes occur along the east sides of Lakes Sorell and Crescent thus suggesting that they, and the tilting which probably produced them, are Mid-Holocene or older. Seismic records over the last decade or so allow epicentres to be recognised on or near the Plateau (fig. 7). This suggests that the Plateau area is still seismically active, although only very mildly so, and therefore presumably slight deformation is still occurring. No signs of movements resulting from seismic activity have yet been seen on the ground.

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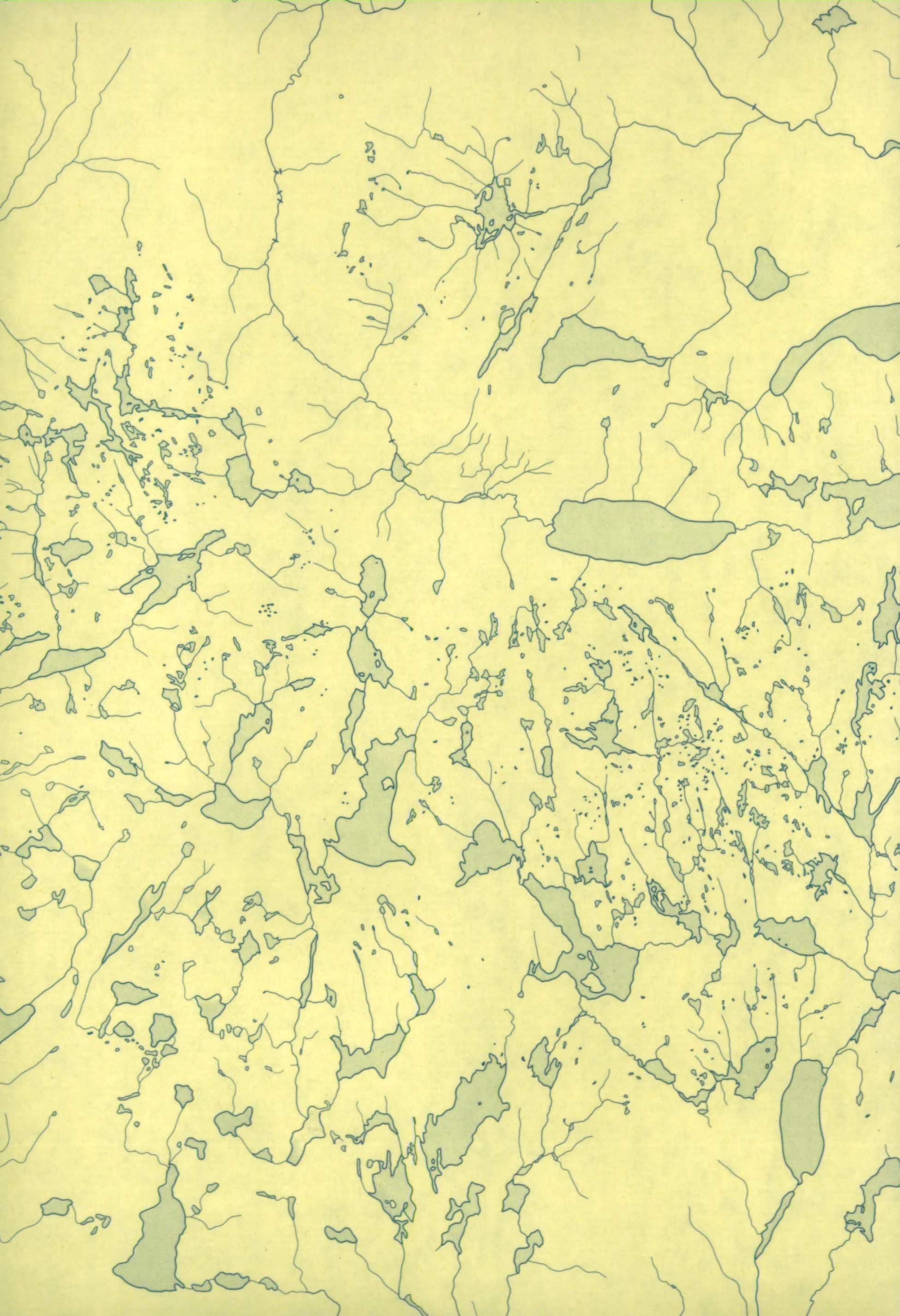

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OCEANIE

(Sous la direction de Jacques AVIAS)

FASCICULE 5

AUSTRALIE

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FASCICULE 5 d

TASMANIA

INTRODUCTION

by

MAXWELL R. BANKS
University of Tasmania

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

INTRODUCTION

by

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Precambrian

The oldest rocks known in Tasmania are older than Middle Cambrian in age and are referred to generally as Precambrian. They extend in an anticlinorial belt about 20 miles wide in a meridional direction from Port Davey in the south to Cradle Mountain in the north (fig. 1). Other areas of Precambrian rocks occur just south of Macquarie Harbour, in an anticlinorial belt stretching from just west of Zeehan to King Island with a branch trending north-easterly to the north coast between Rocky Cape and Penguin, in an anticlinorial belt trending south-south-easterly along the Asbestos Range, and in isolated structural highs in other places such as Dundas, Mount Bischoff, Deloraine, Cressy and Hastings. Although sections have been established in a number of places, no satisfactory system of correlation has yet been found.

Two associations have been recognized in the Precambrian. One of these consists of quartzite, slate, phyllite, schist, amphibolite and conglomerate with sheared pebbles. The schist includes rocks with quartz, muscovite, biotite, chlorite, chloritoid, graphite, garnet, albite and calcite. This association represents a sequence of sandstone (both ortho-quartzite and sub-greywacke suites), siltstone and carbonaceous siltstone, calcareous siltstone, limestone and dolomite with dykes and sills of basic material, the whole now metamorphosed to the greenschist and albite-epidote-amphibolite facies. The other association contains sandstone, quartzite, shale, slate and phyllite with thick dolomite and minor conglomerate beds, intruded by sills and dykes of soda-rich dolerite in the Franklin River area, near Corinna (Interview River dyke swarm) and along the North-West Coast (Cooee Dolerite).

Although these two associations may be of the same age but different metamorphic facies, a number of lines of evidence suggest that the former is the older. Firstly, the two associations are in faulted contact near Ulverstone, and in other places they occur in close proximity, so that the more highly metamorphose rocks are probably the older. An unconformity within the Pre cambrian was postulated many years ago on evidence not nov considered valid, but there is still a possibility that an unconform ity at another level does exist. The amphibolite and dolerit mentioned above are considered to be Precambrian because o their constant association with Precambrian rocks and becaus of their metamorphism. They have been folded with the Pre cambrian rocks and are chemically different from later basi rocks.

On the east coast of King Island a tillite underlies volcani rocks lithologically like those of the Dundas Group (Middle an Upper Cambrian). This tillite and associated graded siltstone ma be Precambrian. Present knowledge thus suggests at least tw cycles of activity in the Precambrian, each cycle consisting o the deposition of considerable thicknesses of sediment of th ortho-quartzite or sub-greywacke suite followed by the intrusio of basic dykes and sills.

Lower and Middle Palaeozoic

Unconformably overlying the Precambrian rocks is th Middle and Upper Cambrian Dundas Group and its correlate The Precambrian rocks were folded and eroded at least twic before deposition of the Dundas Group began in upper Middl Cambrian time. The Dundas Group consists of at least 10,000 fee of greywacke and sub-greywacke conglomerate, sandstone an siltstone with some chert and rare dolomitic limestone, associate with acid and basic volcanic rocks and their pyroclastic equival ents. These comprise at least 11 cycles of sedimentation, eac cycle commencing with conglomerate and terminating with silt stone (now mainly argillite). The volcanic rocks usually occu associated with the siltstone in the cycles. The oldest known fossi include *Ptychagnostus* (?), *Triplagnostus, Peronopsis, Pagetia* an *Lorenzella* (*Ptychagnostus gibbus* Zone of the Middle Cambrian and the youngest *Glyptagnostus reticulatus* and *Protospongi* (*Glyptagnostus reticulatus* Zone of the basal Franconian). Sponge annelids, trilobites, brachiopods, echinoderms and dendroids hav been recorded and show relationship with faunas in Victori Queensland and east Asia.

The volcanic and pyroclastic rocks range from picrite basa to rhyolite in composition and many are referred to as spilite an keratophyre. It has been postulated that the acid members ar albitized and silicified basic lavas and sediments, but there much evidence against this view. Sills and dykes correspondin to the volcanic rocks occur but are rare. The Precambrian rock and the Dundas Group are intruded also by sills and dykes ultrabasic rocks varying in composition from dunite to hornblend gabbro, but chiefly pyroxenite, now largely serpentinized. Thes intrusions tend to be close to the contact between Cambrian an older rocks, especially on the east side of anticlinorial structures. At Adamsfield, at least, the serpentinite is older than Lower Ordovician. At Mount Darwin the Lower Ordovician rocks contain boulders of an underlying granite emplaced in the Dundas Group. This has been used as evidence for a Cambrian granite on the one hand and of granitization of Cambrian sediments in the Middle Devonian on the other. The Dundas Group has been converted to chlorite and sericite schist along a meridional belt from the Mainwaring River in the south almost to Mount Bischoff in the north, and at Round Hill near Moina and in adjacent areas.

The group was deposited in a trough between the Tyennan Geanticline (fig. 2) and the Rocky Cape Geanticline and the Asbestos Range Geanticline, as well as in a trough between the Heemskirk Anticlinorium and the Rocky Cape Geanticline. These troughs were probably part of a eugeosyncline extending at least into Victoria. There is some evidence to suggest that the geanticlines were raised during part of the Stichtan Movement which caused the unconformity immediately below the Dundas Group. Structures occur near Rosebery which may involve unconformities within the Dundas Group but evidence is not yet conclusive. Where the Dundas Group is overlain by Ordovician rocks the relationship is unconformable. The movement producing this unconformity has been called the Jukesian Movement and grouped with the Stichtan Movement as part of the Tyennan Orogeny. As a result of the Jukesian Movement a meridional ridge was raised at least from Macquarie Harbour to Rosebery and controlled sedimentation in the Lower Ordovician. The only mineral of economic significance known definitely to have been introduced during the Cambrian is osmiridium, associated with serpentinite.

The Ordovician System is represented in Tasmania by the Junee Group, which consists of six formations (see Table). Grain size decreases up to the Gordon Limestone with local later reversals to siltstone. Some siltstone also occurs locally in the Owen Conglomerate. The Jukes Breccia is a greywacke breccia in many places and some units in the Caroline Creek Sandstone are sub-greywackes, but with these exceptions the group contains sediments of the ortho-quartzite suite. The lower formations show rapid variations in thickness but the higher ones are more uniform. The group is widely distributed from Ida Bay and Beaconsfield in the east to Zeehan and Heazlewood in the west, and from north to south throughout the island, but it apparently does not overlap onto the Rocky Cape Geanticline. There is an overlap progressively from the Jukes Breccia upwards as the Ordovician sea covered the lands raised by the Jukesian Movement and these lands were reduced by erosion. The correlate of the Jukes Breccia near Adamsfield contains *Scaevogyra,* trilobites and brachiopods, and is Upper Cambrian or Lower Ordovician in age. The Caroline Creek Sandstone at Caroline Creek, near Latrobe, contains *Carolinites, Etheridgaspis* and other trilobites, indicating an Upper (?) Arenigian age, and the

Florentine Valley Mudstone near Maydena contains *Asaphopsis*, *Carolinites*, *Tritoechia*, *Syntrophopsis* and *Didymograptus*, indicating a Middle Arenigian age. As the Florentine Valley Mudstone overlies the Caroline Creek Sandstone, this shows that the Caroline Creek Sandstone is a diachronous formation, being older in the Maydena area than at Caroline Creek.

The Gordon Limestone contains *Manchuroceras*, *Suecoceras*, *Allocotoceras* and other cephalopods at the base near Adamsfield which indicate an Upper Arenigian age, and the top contains numerous corals, including *Eofletcheria*, *Catenipora*, and *Palaeofavosites*, and is probably Upper Ordovician. In the Linda Valley, near Queenstown, the limestone is overlain by a siltstone, the « Fenestella Shale », which contains phylloporines. Similar beds occur at Queenstown and Zeehan and are richly fossiliferous in both places. This formation provides a gradation from the limestone into the overlying Eldon Group.

The change from Gordon Limestone up into siltstone and sandstone is thought to be due to a rise in the source area to the west. The postulated rise in the source area may be genetically connected with the Benambran Orogeny in New South Wales. The Eldon Group is almost as widespread as the Junee Group. It consists of sandstone, siltstone and limestone of the orthoquartzite suite. There is a general reduction in grainsize from the base upwards, but superimposed on this trend are three major alternations of sandstone and siltstone. The Crotty Sandstone contains *Camarotoechia* in several places and *Monograptus* in the Frenchman's Cap area. The Amber Slate contains the ostracode *Gillatia* at Zeehan, which suggests correlation with Upper Llandoverian rocks in Victoria, and it contains *Monograptus* and *Cyrtograptus* in the Frenchman's Cap area, which suggest a Middle Silurian age for part of it. The Florence Sandstone contains *Notoconchidium*, *Pleurodictyum* and *Maoristrophia*, which suggest that it is at least partly Devonian. The Bell Shale contains fossils such as *Pleurodictyum*, *Notanoplia*, *Plectodonta*, *Australocoelia* and *Trimerus*. The affinities of the fauna of the Eldon Group are with Victoria and New Zealand except for the presence of *Australocoelia* at Zeehan which shows some affinity with South Africa and South America.

In north-eastern Tasmania the Mathinna Group consists dominantly of sub-greywacke, siltstone and quartzite, with some plant fragments such as *Hedeia* and *Hostimella* and rare fragmentary marine fossils. Lavas and tuffs have been recorded in a number of places, but these reports have not been supported by petrological description. Near Beaconsfield rocks thought to be Mathinna Group overlie Gordon Limestone, possibly with a disconformity, and this and the presence of the primitive vascular plants suggests approximate equivalence to the Eldon Group. However, the correlation is very tentative.

Structure

The Junee and Eldon Groups in the west and the Mathinna Group in the north-east were folded after the Lower Devonian but before the Permian. This folding is usually correlated with the Middle Devonian Tabberabberan Orogeny in Victoria but no conclusive evidence of its age is known in Tasmania. It seems that the anticlinoria (later geanticlines) raised by the Tyennan Orogeny in the Cambrian were further folded at this time, and the Ordovician to Lower Devonian sediments were folded into anticlinoria and synclinoria.

The major structures produced were a series of anticlinoria and synclinoria (fig. 2). In the far north-west the Heemskirk Anticlinorium trends north-north-west from near Zeehan to King Island, where it swings to the north-north-east. To the east is a synclinorium trending somewhat east of north which may be referred to as the Montagu Synclinorium. Near the mouth of the Pieman River the Heemskirk Anticlinorium bifurcates and a major anticlinorium trends north-north-east to north-east (Rocky Cape Geanticline). East and south-east of these anticlinoria is a major synclinorium extending from south of Macquarie Harbour through Zeehan, the Huskisson River, Gunn's Plains, Melrose and Railton. This might be referred to as the Zeehan-Melrose Synclinorium. It is divided by a minor anticlinorial ridge trending north from Macquarie Harbour to Mount Lyell and from Dundas, west of Rosebery, east of St. Valentine's Peak to Sheffield and Deloraine. This has been called the West Coast Range or Porphyroid Anticlinorium. East of the Zeehan-Melrose Synclinorium is the Tyennan Geanticline with an overall meridional trend. The main rocks (Precambrian) in this geanticline, however, do not show a meridional trend, but numerous swings in trend (fig. 2). A minor anticlinorium trends north-north-west along the Asbestos Range west of Beaconsfield. In the north-east, trends vary from north-west near the Tamar River to north-north-west near Avoca and almost north at Scamander and St. Marys.

Folding of the Mathinna Group has given rise to folds with westerly dipping axial planes and wave-lengths of the order of a few hundred yards. The major structures are crossed by minor folds which vary in direction (fig. 2). Faulting is associated with the folding, and in the West Coast area it consists of meridional wrench faults (west side north and up), north-westerly overthrusts dipping to the south-west, and north-easterly normal faults. The structures in this area have been explained as due to a shear in the basement, west side north, affecting the overlying sediments (Carey, 1953). After folding and faulting of the Lower and Middle Palaeozoic sediments, serpentine may have been intruded into them, but no unequivocal evidence of this is known. Further examination of a case quoted as indicative of a Devonian age for the Wilson River Serpentinite shows that it may have been faulted with the Eldon Group and could be Cambrian.

Granitic intrusions followed the folding. Their composition varied from diorite to alaskite, but the main rock type is granodiorite. There were later minor intrusions of aplite, pegmatite, hornblende lamprophyre and dolerite. Copper, lead, tin, zinc, tungsten and gold were introduced about this time. In Western Tasmania, the granitic intrusions are found along the margins of the Heemskirk Anticlinorium and within the Zeehan-Melrose Synclinorium near its western margin as well as close to the western margin of the Tyennan Geanticline. The main batholiths are in the north-east and seem to follow more or less meridional trends, but their relationship to the structure is not yet clear. At St. Marys a hypersthene porphyrite cuts across the axes of the folds and across the contact between Mathinna Group sediments and granodiorite, and may be a later intrusion (or extrusion).

Upper Palaeozoic

After the Devonian, the older sediments and igneous rocks were eroded until some time late in the Carboniferous or early in the Permian. At that time Tasmania was apparently fairly low-lying, with a relief of one or two thousand feet only. The western half at least was at this stage covered by an ice-sheet, and the eastern half may have been land surface or covered by a shallow sea. The Permian succession consists of two major cycles of marine sediments separating three freshwater sequences. In the western half, in most places the basal formation is a tillite, the Wynyard Tillite and its correlates. The presence of varved siltstone and lack of marine fossils suggest that this is a terrestrial deposit.

The tillite is followed by the Quamby Group (Quamby Mudstone of WELLS, 1957) which includes dark pyritic siltstone with glendonites (Woody Island Siltstone), fossiliferous glendonitic sandstone, conglomeratic siltstone, and a unit of oil shale rich in *Tasmanites punctatus*. This marine group is followed by another, the Golden Valley Group (Golden Valley Formation of WELLS, 1957) with richly fossiliferous siltstone, sandstone and limestone. The limestone contains *Calcitornella stephensi, Geinitzina triangularis, Eurydesma cordatum, Stenopora tasmaniensis* and *S. johnstoni,* and is thought to be Lower Artinskian in age. The marine sequence is followed by a freshwater succession, the Mersey Group (new term for Mersey Coal Measures) (equivalent to Liffey Group, Faulkner Group), which consists mainly of quartz sandstone with carbonaceous siltstone and some coal. In the Hobart area this freshwater succession is represented by two cyclothems (Faulkner Group).

The Mersey Group and equivalent beds contain *Glossopteris, Gangamopteris* and *Noeggerathiopsis*. Oil shales (Don Valley Black Shale, etc.) occur in this horizon near Nook, at Preolenna, Mount Pelion and Lilydale. The higher marine sequence consists of three groups, Cascades Group, « Woodbridge » Group, and

Ferntree Group. The lowest, Cascades, group consists of limestone and fossiliferous siltstone, and is characterized by *Lyroporella, Pterotoblastus, Taeniothaerus subquadratus, Strophalosia typica, Cladochonus* and *Thamnopora*. The « Woodbridge » Group consists of alternating sandstone and siltstone and contains *Stenopora crinita* and other fossils. The Ferntree Group is an alternation of fissile and non-fissile siltstone with some beds of sandstone and conglomerate. There are rare marine fossils in it. This higher marine succession is thought to be Upper Artinskian and Kungurian in age. The highest Permian formation is the Cygnet Coal Measures, a formation of quartz sandstone, siltstone and some coal, which contains *Glossopteris, Gangamopteris* and *Vertebraria australis.*

The marine sediments of the Permian in Tasmania all contain erratics and belong to the sub-greywacke suite. Vulcanism is represented by some metabentonite in the Cascades Group. The system is thickest in south-eastern Tasmania, about 2,500 feet. Almost all the marine formations show banding, i.e., alternation superimposed on the overall freshwater-marine cycle.

Mesozoic

Where the Cygnet Coal Measures are developed completely, the Triassic rests conformably on the Permian, but where this formation is incomplete or absent there is a disconformity. The Triassic in Tasmania is a completely freshwater sequence and because of lack of good marker beds the succession is not yet clear. The lower part consists of siliceous sandstone and siltstone at least 1,100 feet thick and includes some red beds. It is cross-bedded, ripple-marked and slumped, and near the base contains a granule or pebble conglomerate. Also near the base in some areas are a bed containing halite and one with epsomite.

The sandstone and siltstone contain plant fossils including *Neocalamites, Thinnfeldia* and *Cladophlebis* as well as rare fish such as *Acrolepis* and very rare reptilian bones (captorhinid). In contrast to the Permian rocks, these sediments are well sorted. They were deposited under lacustrine or swampy conditions, perhaps in a monsoonal climate. Higher in the sequence is a sandstone formation rich in andesine, known locally as the « Feldspathic Sandstone », and associated with claystone beds and at least 8 coal seams. The « Feldspathic Sandstone » contains much chlorite, a little biotite and quite a few fragments of andesitic material, and in places could best be considered as tuffaceous but not necessarily tuff. The claystone associated with the coal seams is richly fossiliferous with *Neocalamites, Cladophlebis, Thinnfeldia, Johnstonia, Stenopteris, Phoenicopsis, Pterophyllum, Linguifolium, Ginkgo, Sagenopteris* and other plants which indicate a Middle Triassic age.

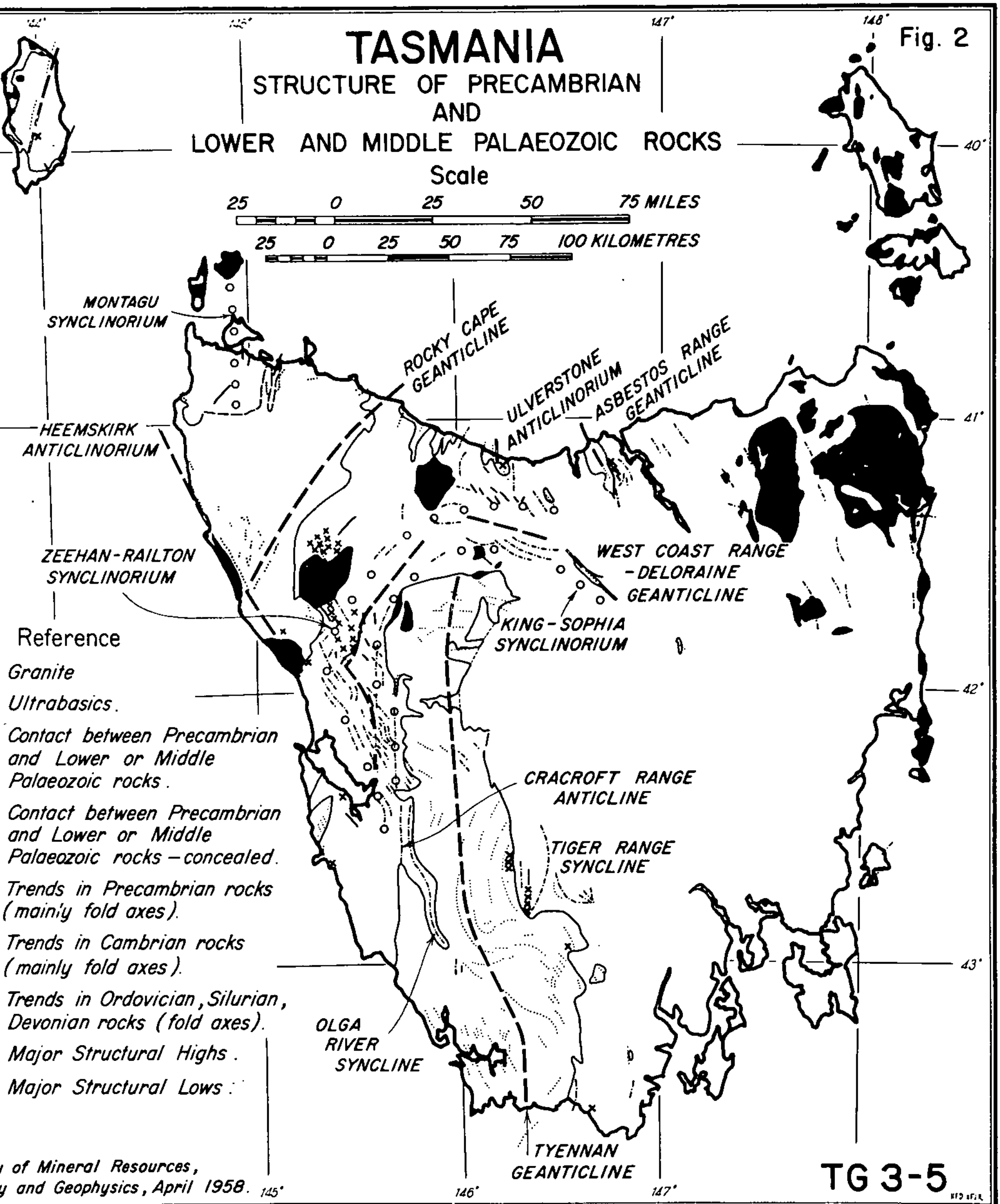
After the « Feldspathic Sandstone » and coal measures were deposited, a large volume (at least 10,000 cubic miles) of dolerite was intruded through the Precambrian and Lower and Middle Palaeozoic sediments as dykes to spread out through the Permian and Triassic sediments as sills and dykes. The sills are consistently slightly transgressive. They vary in thickness from an inch or so up to at least 1,600 feet and are especially common on the horizon of siliceous siltstone in the lower part of the Triassic. The dykes commonly occupy faults between blocks of sediments, one of which has moved up under the influence of the intrusion. The dolerite is a tholeiitic type with rare acid and common basic segregations. The dolerite intrudes Middle Triassic sediments and in places is faulted and overlain by freshwater sediments of Lower Tertiary age. A surface including dolerite was lateritized before the faulting assigned to the Upper Cretaceous or Lower Tertiary. All these lines of evidence still leave a considerable time range, and within it, the dolerite is considered as Jurassic chiefly by analogy with the chemically similar Karroo Dolerites of South Africa.

At Cygnet in the south-eastern part of the State is a small stock of alkaline syenite associated with a radial dyke system of alkaline rocks such as garnet-sanidine porphyry. These intrude Permian rocks and dolerite and are faulted in several places, but as the age of the dolerite and the age of the faulting are both uncertain, the age of the alkaline stock remains indeterminate too.

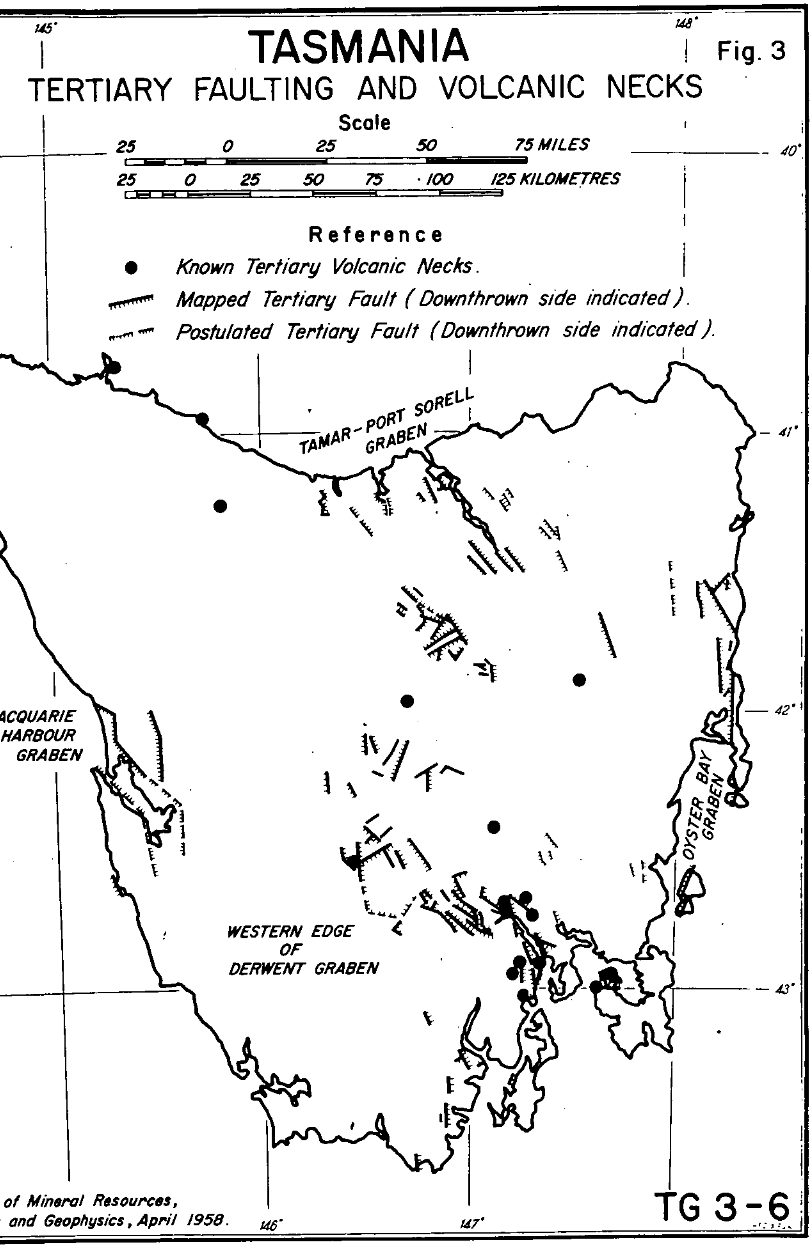
Cainozoic

After intrusion of the dolerite and the accompanying block faulting, there is an hiatus in the geological history of the State, possibly until the early Tertiary. Because of the development of laterite and bauxite on the dolerite in a number of places, a period of peneplanation under monsoonal conditions has been postulated. Late in the Cretaceous or very early in the Tertiary the lateritized surface was faulted and tilted and covered by lacustrine sediments in the Launceston and Ouse grabens. The faulting was all of the tensional type and produced grabens at Port Sorell, the Launceston area, Oyster Bay, Derwent River area, and Macquarie Harbour. These grabens were filled or partly filled with gravel, sand, clay and lignite, with fossil leaves, stems, cones, seeds and inflorescences and rare freshwater pelecypods. Only the sediments in the Launceston Graben and at Ouse have been dated with any degree of certainty, and they contain a spore *Trisaccites,* which in Victoria is not known above the Eocene. There is no reliable evidence on the ages of the sediments in the other grabens and they may not be contemporaneous. The lacustrine sediments were eroded to depths of several hundred feet and then basalt was poured out into the valleys so produced, often to below present sea level. This basalt was bauxitized at several places near Launceston.

The age of these basalts is not known. In the far north-western corner of the island, on King Island and on Flinders



TASMANIA
STRUCTURE OF PRECAMBRIAN
AND
LOWER AND MIDDLE PALAEOZOIC ROCKS
Scale
25 0 25 50 75 MILES
25 0 25 50 75 100 KILOMETRES
Fig. 2
MONTAGU SYNCLINORIUM
HEEMSKIRK ANTICLINORIUM
ZEEHAN-RAILTON SYNCLINORIUM
ROCKY CAPE GEANTICLINE
ULVERSTONE ANTICLINORIUM
ASBESTOS RANGE GEANTICLINE
WEST COAST RANGE - DELORAINE GEANTICLINE
KING-SOPHIA SYNCLINORIUM
CRACROFT RANGE ANTICLINE
TIGER RANGE SYNCLINE
OLGA RIVER SYNCLINE
TYENNAN GEANTICLINE
Reference
Granite
Ultrabasics.
Contact between Precambrian and Lower or Middle Palaeozoic rocks.
Contact between Precambrian and Lower or Middle Palaeozoic rocks – concealed.
Trends in Precambrian rocks (mainly fold axes).
Trends in Cambrian rocks (mainly fold axes).
Trends in Ordovician, Silurian, Devonian rocks (fold axes).
Major Structural Highs.
Major Structural Lows.
of Mineral Resources,
y and Geophysics, April 1958.
147°
148°
40°
41°
42°
43°
145°
146°
147°
TG 3-5


TASMANIA
Fig. 3
TERTIARY FAULTING AND VOLCANIC NECKS
Scale
25 0 25 50 75 MILES
25 0 25 50 75 100 125 KILOMETRES
Reference
Known Tertiary Volcanic Necks.
Mapped Tertiary Fault (Downthrown side indicated).
Postulated Tertiary Fault (Downthrown side indicated).
145°
148°
40°
41°
42°
43°
146°
147°
TAMAR-PORT SORELL GRABEN
ACQUARIE HARBOUR GRABEN
OYSTER BAY GRABEN
WESTERN EDGE OF DERWENT GRABEN
of Mineral Resources,
and Geophysics, April 1958.
TG 3-6

PERIOD	EPOCH	ROCK UNITS	THICKNESS (in feet)	FOSSILS	IGNEOUS ACTIVITY	TECTONIC ACTIVITY	OTHER FEATURES
QUATERNARY	RECENT	Alluvium, dunes, beaches etc.					
	PLEISTOCENE	High level beaches, swamp & lake deposits, terraces, fossil dunes, tills, varves		*Nototherium, Thylacoleo, Acacia*		Tensional Faulting ?	Two phases of glaciation. Margaret (began about 26 000 yrs. ago). Yolande
TERTIARY	PLIOCENE				Basalt		Disconformity
	MIOCENE	Bryozoal calcarenites	250	*Lepidocyclina (Trybliolepidina) Aturia australis, Prosqualodon Wynyardia Sherbornina atkinsoni*			
	OLIGOCENE	Table Cape Group	80				Disconformity
					Basalt		
	EOCENE	Launceston Beds	1 000	*Trisaccites*		Tensional Faulting ?	Disconformity Lacustrine, paludal, fluviatile
	PALAEOCENE			*Nothofagus*		Tensional Faulting	
CRETACEOUS		Laterite and Bauxite					Peneplanation
JURASSIC					Alkali syenite ? Dolerite	Tensional Faulting	
TRIASSIC		« Feldspathic Sandstone »		*Phoenicopsis, Linguifolium Johnstonia*	Tuffs (intermediate)		Includes Coal Measures
		Knocklofty Formation (Sandstone & Siltstone)	1 200 +	*Thinnfeldia Cladophlebis*			Salt and Epsomite low in sequence
PERMIAN	TARTARIAN KAZANIAN	Cygnet Formation		*Glossopteris, Gangamopteris, Vertebraria indica*			Disconformity in some places Lacustrine, paludal etc.
		Ferntree Group		spiriferids			Marine with erratics
	KUNGURIAN	« Woodbridge » Group		*Stenopora crinita*			
		Cascades Group	2 300 +	*Taeniothaerus subquadratus*	Meta-bentonite		
	ARTINSKIAN	Mersey Group		*Glossopteris, Gangamopteris Noeggerathiopsis*			Lacustrine, paludal ; cyclothems
		Golden Valley Group		*Calcitornella, Eurydesma, Keeneia*			Marine with erratics
		Quamby Group		*Tasmanites punctatus*			
	SAKMARIAN	Wynyard Tillite					
CARBONIFEROUS							Erosion then glaciation
DEVONIAN	UPPER					Folding	Unconformity
	MIDDLE				Emplacement of St. Marys Porphyry Intrusion of Granite	Folding	Unconformity (?)
	LOWER	Eldon Group = ? Mathinna Group		*Hostimella*			
		Bell Shale	5 000	*Trimerus, Australocoelia Maoristrophia, Pleurodictyum*			
SILURIAN	Ludlovian	Florence Sandstone		*Notoconchidium Pleurodictyum*			
	Wenlockian	Siltstone					
		Keel Quartzite					
		Amber Slate		*Cyrtograptus, Tentaculites Gillatia*			
	Llandoverian	Crotty Sandstone		*Camarotoechia synchoneua, Monograptus*			
ORDOVICIAN	Cincinnatian Gamachian	Junee Group « Fenestella Shale »					Non-sequence in places
	Richmondian Maysvillian Edenian						
	Champlainian Trentonian Blackriveran Chazyan	Gordon Limestone	6 000	*Tetradium* *Maclurites, Girvanella, Manchuroceras, Piloceras*			One major cycle of sedimentation
		Florentine Valley Mudstone	300	*Tritoechia Didymograptus*			
	Canadian	Caroline Creek Sandstone	1 000	*Carolinites, Asaphopsis*			
		Owen Conglomerate	1 200			Some faulting	Minor unconformity
		Jukes Breccia	1 500				
CAMBRIAN					Intrusion of Darwin granite	Folding (Jukesian Movement)	Unconformity
	Upper Trempealeauan				? Intrusion of Ultrabasic Rocks		
	Franconian	Pyritic shales (Huskisson River)		*Glyptagnostus*			At least eleven cycles of sedimentation (greywacke or subgreywacke conglomerate, sandstone, argillite) may be minor unconformities within group.
	Dresbachian						
	Middle	Dundas Group (Formations local only)	10 000 +	*Pseudagnostus Blackwelderia* Dendroids *Triplagnostus, Pagetia*	Basic to acid lavas; Spilitic suite	Folding ?	
	Lower					Folding	Unconformity
PRE-CAMBRIAN		? King Island Tillite			Cooee Dolerite (and correlates)		
		Rocky Cape Group (and correlates) ? = Carbine Group	10 000				Quartzites, slates and thick and thin dolomites
		Fincham, Franklin, Mary, Joyce Groups (and correlates) ? = Davey Group	20 000		Amphibolites	Folding and metamorphism	Unconformity Quartzites, phyllites ; mica, chlorite, garnet schists; garnet gneisses ; minor thin dolomite

sland deposition of marine sediments, especially bryozoal calca-enites, began late in the Oligocene and continued till late in the ower Miocene. Near Wynyard a basalt flow is overlain by these ediments and they in turn are overlain by basalt. The marine ediments contain *Sherbonina atkinsoni, Aturia australis, Pros-ualodon davidi* and *Lepidocyclina (Trybliolepidina)* among many ther fossils. At Wynyard the oldest known marsupial from ustralia, *Wynyardia bassiana,* occurs associated with *Aturia* nd *Prosqualodon.* Valleys a couple of hundred feet deep were ut in these marine sediments and then filled with basalt to below resent sea level. Thus some at least of the basalt is Middle Mio-ene or younger.

Pleistocene marine sediments occur on Flinders Island but re not known elsewhere in the State. A Pleistocene swamp eposit near Smithton contains bones of *Nototherium* and other rge marsupials, and a similar swamp occurs at the south-astern end of King Island. Of especial interest are the features f mountain and valley glaciation in Tasmania. Formerly three hases of glaciation were postulated, the Malanna, Yolande and largaret, but recent work indicates that there are only two. The 'olande deposits reach down to about 200 feet above sea level n the Henty River and the Margaret deposits are higher. Wood ssociated with the advance stage of the Margaret Phase was ated recently at 26,400 ± 800 years, and indicates rough con-emporaneity of the beginnings of the Margaret Phase and the /isconsin Phase in North America.

IMPRIMERIE LOUIS JEAN - GAP -

Paper No. 13

for STRUCTURAL MAP OF TASMANIA

see pocket.

UNIVERSITY OF TASMANIA

DEPARTMENT OF GEOLOGY

Publication No. 157

Geology and Mineral Deposits

MAXWELL R. BANKS

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ATLAS OF TASMANIA

GEOLOGY AND MINERAL DEPOSITS

Maxwell Banks

GEOLOGY and MINERAL DEPOSITS

M. R. Banks

PRECAMBRIAN

THE OLDEST rocks in Tasmania consist of an assemblage more than 20,000 feet thick of quartz, albite, mica and garnet schists, quartzites, phyllites, slates, amphibolites with eclogitic nodules, and stretched pebble conglomerates. These rocks, originally sandstone, siltstone, conglomerate and basic igneous rocks of the olivine basalt suite, have been metamorphosed to the greenschist facies.

This assemblage was deformed during the Frenchman Orogeny of which there were two phases, the later producing large recumbent folds. A north-northeasterly trending geanticline may have been formed by this orogeny (Figure 14).

Erosion of areas uplifted during the Frenchman Orogeny resulted in deposition first of sand and later silt in areas adjacent to the geanticline. Subsequently uplift, possibly along the position of the Heemskirk Anticlinorium, Rocky Cape and Tyennan Geanticlines (Figures 14, 16), led to deposition of sand and gravel containing pebbles of quartzite and phyllite. Dolomite, basalt and tuff occur with sands (quartzose subgreywackes) and silts, now metamorphosed to slate and phyllite. The thickness of this assemblage is at least 15,000 feet.

These sediments and volcanic rocks were intruded by dolerite, folded during the Penguin Movement and subjected to further dolerite intrusion. One of the dolerites is at least 700 million years old. Amphibolites at Long Plains and the Savage River containing lenses of titaniferous magnetite, intrude quartzites, phyllites, slates and schists as dykes. These pre-Middle Cambrian amphibolite intrusions may have been emplaced between the phases of the Frenchman Orogeny, or may have been associated with the Penguin Movement. The concentration of iron minerals may be magmatic segregations, formed in place, concentrations formed at depth prior to the intrusion of the amphibolite, or formed in situ by flowage differentiation.

It is likely that a long erosion interval followed the Penguin Movement. Later, there was slight downwarping after which about 4,000 feet of dolomite and limestone, some of it oolitic, associated with rare clastic sediments were deposited in a north-northwesterly trending shallow trough flanked by lowlands (Figure 14). These calcareous beds rest on the older rocks with a low angle regional unconformity.

Following deposition of these calcareous beds the Tyennan Geanticline rose along a meridional belt not quite in the same position as the earlier geanticlines (Figure 15).

CAMBRIAN

Cambrian rocks rest unconformably on older rocks on the western margins of the geanticline and in northern and southern areas but are concordant with the dolomitic association west of the Tyennan Geanticline, where there was, however, a change in the type of sedimentation and rate of sinking of the depositional area.

The Crimson Creek Argillite, 10,000 feet thick, concordantly overlies the dolomitic association in western Tasmania. This unit, probably Lower Cambrian, consists predominantly of siltstones with thin greywacke, dolomitic siltstone, tuffs, rare lavas, conglomerates and chert. The conglomerates contain schist, tuff, quartzite and granitic pebbles.

A belt of volcanoes, the Mt Read Volcanic Arc, developed close to the Tyennan Geanticline on the western, northern and eastern sides during the Cambrian. The volcanic rocks produced in this belt, the Mt Read Volcanics, consist of acid, intermediate and rare basic lavas, all of the spilitic suite, ignimbrites and tuffs with a total thickness of about 10,000 feet. Most of the acid volcanic rocks occur close to the Tyennan Geanticline. Basic rocks predominate further from the geanticline in most places but some are intercalated with acid rocks. The volcanic rocks are pre-Ordovician and may be Lower Cambrian or Middle and Upper Cambrian.

A sea, possibly with islands along the Rocky Cape Geanticline and near Devonport, flanked the Mt Read Volcanic Arc. In this sea, Middle and Upper Cambrian siltstones, greywackes, paraconglomerates, rare limestone and dolomite,

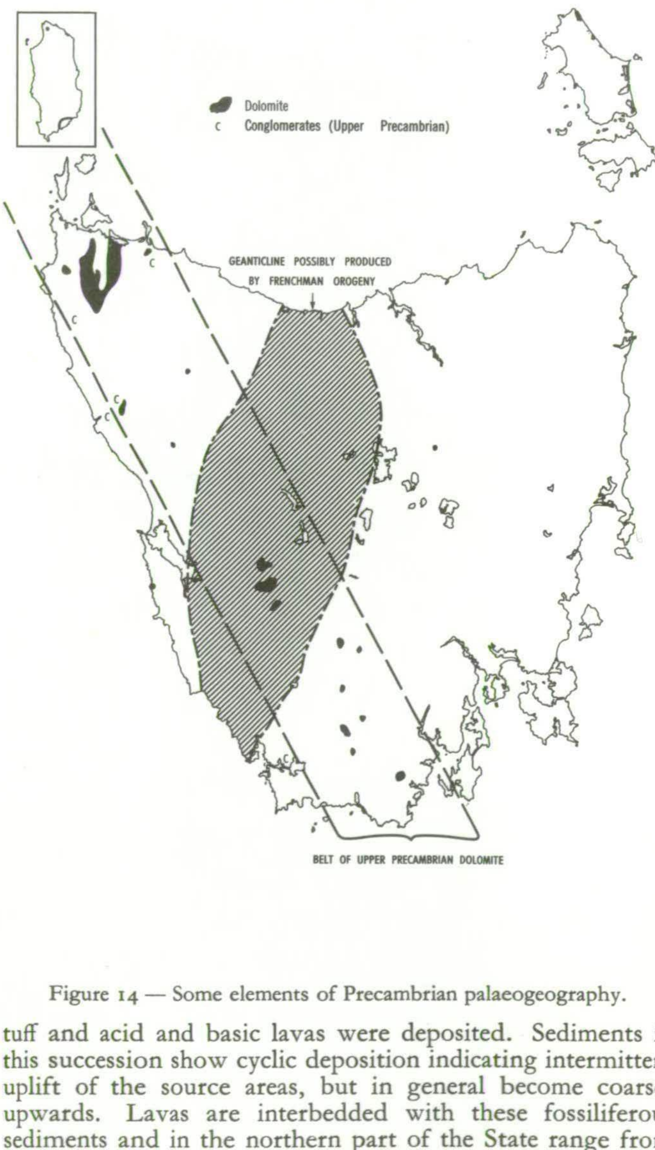


Figure 14 — Some elements of Precambrian palaeogeography.

tuff and acid and basic lavas were deposited. Sediments in this succession show cyclic deposition indicating intermittent uplift of the source areas, but in general become coarser upwards. Lavas are interbedded with these fossiliferous sediments and in the northern part of the State range from early Middle Cambrian to older or Upper Cambrian. Earth movements occurred near Ulverstone early in the Middle Cambrian and at the base of the Upper Cambrian. Trilobites, dendroids, echinoderms, brachiopods, gasteropods and sponges lived in the sea and show the age as Lower Middle Cambrian to Middle Upper Cambrian.

Pyroxenite and other ultrabasic rocks, now partly altered to serpentinite, were intruded before the Middle Upper Cambrian as concordant or almost concordant sheets along or close to the Precambrian-Cambrian contact, and as sills and dykes in Upper Precambrian and Cambrian rocks. The intrusions are concentrated in a belt along the eastern side of the Rocky Cape Geanticline and another belt 30 to 50 miles further east along the eastern side of the Tyennan and Asbestos Range Geanticlines. These geanticlines were at least partially emergent during the Cambrian. Osmiridium occurs in schlieren, possibly due to flowage differentiation, in pyroxenite and peridotite at Adamsfield, Bald Hill, the Wilson River, Dundas and elsewhere. Osmiridium was redistributed as a beach placer at Adamsfield as early as Lower Franconian (Middle Upper Cambrian) time. Nickel and copper sulphides occur in these intrusions near Zeehan and at Bald Hill, possibly concentrated by flowage differentiation. This process may also have concentrated copper nickel bodies at Bald Hill and the magnetite bodies at Tenth Legion near Zeehan. The Darwin and Murchison Granites were intruded as crudely concordant bodies into the core of the volcanic pile of the Mt Read Volcanic Arc in western Tasmania in pre-Ordovician time.

Towards the end of Cambrian time, during the Jukesian Movement, rejuvenation of the Tyennan Geanticline produced a steeply dipping zone of Cambrian rocks along the western margin of the Geanticline, gentle folding elsewhere and perhaps uplifted a ridge between Dundas and Queenstown (the Dundas Ridge).

ORDOVICIAN

Early in the Ordovician fanglomerates, such as the Jukes Conglomerate, developed as screes up to 1,400 feet thick from volcanic rocks flanking the Tyennan Geanticline and from other high areas. Alluvial cones and fans (of siliceous gravels and sands) derived from the disintegration of the Precambrian rocks of the geanticlines spread on to low areas bordering the Tyennan Geanticline and on the eastern side of the Asbestos Range and Rocky Cape Geanticlines. Early in the Ordovician the siliceous gravels and sands were deposited against the Dundas Ridge at Zeehan and overlapped onto it near Queenstown from the Tyennan Geanticline on the east. These conglomerates and sandstones (the Owen Conglomerate and its correlates) are more than 2,400 feet thick.

As the geanticlines were eroded during the Arenigian, the sea transgressed, depositing about 1,000 feet of sand (the Caroline Creek Sandstone and its equivalents) in shallow water over the Tyennan Geanticline, the Dundas Ridge and part of the Rocky Cape Geanticline as well as in the intervening low areas. This sand passes up and towards south central Tasmania into richly fossiliferous siltstone up to 1,000 feet thick containing Middle and Upper Arenigian fossil shells and graptolites. The siltstone is overlain by a thick formation (5,000 feet) of shelly limestone, the Gordon Limestone, containing many shelly fossils, deposited in shallow water from Upper Canadian to Upper Ordovician time. The limestone contains dolomite, some bitumen and pyrite and is stylolitic throughout and a few sandstone and siltstone bands are present in it. The limestone is overlain by a siltstone of Upper Ordovician age a few feet thick. Thus during most of the Ordovician, Tasmania was covered by shallow, probably warm seas, in which sandstone, siltstone and limestone were deposited successively on a slowly sinking stable shelf. This succession passes eastwards into siltstone containing thin sandstone bands in northeastern Tasmania.

SILURIAN AND DEVONIAN

Uplift of areas in northwestern Tasmania and faulting near Beaconsfield in northern Tasmania occurred near the end of the Ordovician and initiated a period of instability which lasted until the Middle Devonian. Deposition of the Eldon Group commenced with shallow water marine sandstone and pebbly sandstone, which were overlain by alternating sandstone and siltstone containing some lenses of coralline limestone, the total thickness of the Eldon Group being about 6,000 feet. One source area northwest of Zeehan has been suggested. This marine succession contains numerous shells on some horizons, and graptolites of Lower Llandoverian, Wenlockian and Lower Ludlovian age have been found. The Eldon Group was deposited on an unstable shelf bordering a geosyncline to the east in Silurian and Lower Devonian times.

The Eldon Group passes northeastwards and eastwards into the Mathinna Beds which are at least 6,000 feet thick and consist of siltstone and poorly sorted sandstone. Few fossils are present. Siltstone was the normal deposit in the deeper waters of the geosynclinc in northeastern Tasmania during this interval but turbidity currents, mainly from the southwest, brought in sand from shallower water from time to time.

At Point Hibbs south of Macquarie Harbour the Spero Bay Group consists of 2,200 feet of shallow water conglomerate, sandstone, siltstone and richly coralline limestone, probably Upper Lower Devonian and Lower Middle Devonian in age. The Spero Bay Group records the erosion of a

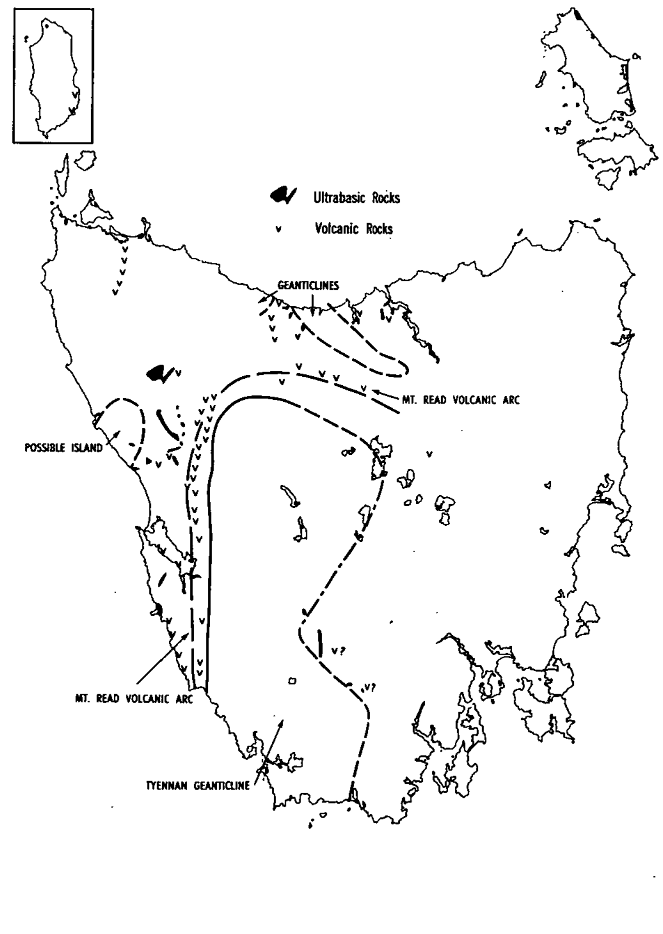


Figure 15 — Some elements of Cambrian palaeogeography.

newly uplifted area until the supply of clastic grains from it was so small that only limestone was formed in the shallow sea close to the shoreline, and then rejuvenation and a change in the source area.

DEVONIAN OROGENY AND IGNEOUS ACTIVITY

A new basin developed at Point Hibbs in Upper Lower Devonian time and movements occurred during deposition of the coralline limestone of the Spero Bay Group and subsequent to it. Later the Spero Bay, Mathinna, Eldon and Junee Groups as well as older rocks were folded.

Two main movements during the Tabberabberan Orogeny are indicated by the structure of the folded rocks; the earlier produced long wavelength structures parallel to the margins of the Tyennan, Rocky Cape and Asbestos Range Geanticlines; the latter produced north-northwest to northwest trending short wave length, lower amplitude anticlinoria and synclinoria (Figure 16). The structure in the lithologically uniform Mathinna Beds consists of anticlinoria and synclinoria. This contrasts with the more complicated structure of the Junee, Eldon and Dundas Groups further west in which thrusts and wrench faults are superimposed on the folds. Latitudinal compression, producing major folds, followed by meridional dextral simple shear, or northeast-southwest compression with deflection of the forces along pre-existing structural features have been suggested to explain the structure of western Tasmania. On a State wide basis the earlier folds may be due to differential vertical movement followed by east-northeast compression or by meridional dextral simple shear or by latitudinal sinistral simple shear. Another way in which the present structural pattern of the early Palaeozoic rocks may have been produced is by compression from 65° to 70° with early development at low stress of broad low structures parallel with the Tyennan, Rocky Cape and Asbestos Range Geanticlines with slight movement of the blocks and of the sediments on to the blocks, possibly all under a primary thrust regime. Intensification of this stress led to intensification of folding in the Mathinna Beds under the same regime, but to development of folds, thrusts and wrenches further west where rigid geanticlinal blocks and wedges of Owen Conglomerate produced a secondary wrench regime. Further detailed analyses of the structures produced by the Tabberabberan Orogeny are necessary before a full assessment of the stresses is possible.

Underground drainage developed in folded Gordon Limestone at Eugenana and spores of Upper Devonian age were washed into the caves produced. The cave deposits are unfolded. Thus the orogeny was completed prior to the Upper Devonian in Tasmania.

Alkaline and calcalkaline, acid to intermediate plutonic intrusions cut across the folded Palaeozoic rocks with sharp margins and narrow contact aureoles. Adamellite is the most common of these intrusions but multiple intrusions with acid and basic differentiates occur. The intrusions have been dated as Upper Devonian and possibly Lower Carboniferous. The batholiths and stocks were apparently intruded along the zones of inflection between major anticlinoria and synclinoria causing local updoming.

METALLOGENESIS

Granitic Association: The granitic rocks intruded after the Tabberabberan Orogeny introduced tin, tungsten, zinc and lead into the folded rocks to form concentrations of economic value in many places. Veins, pipes, dykes and nodules of greisen containing cassiterite or of quartz, cassiterite and tourmaline occur in granite at Heemskirk and Blue Tier. Scheelite occurs in thin bands in a thermally metamorphosed impure limestone, now a skarn in an Upper Precambrian succession of mudstone, impure dolomite and limestone, now all contact metamorphosed by granodiorite, at Grassy on King Island.

Cassiterite and wolframite occur in quartz veins in a steeply west-dipping zone above a cupola of granodiorite intruded into Mathinna Beds at Aberfoyle in northeastern Tasmania, and, nearby at Storeys Creek, in veins with shallow southwesterly dips. These minerals also occur in fissure-filling veins, mainly along faults, but also in joints and along bedding planes in the Lower Ordovician sandstone and overlying impure limestone at Moina where these rocks are close to the Dolcoath Granite.

Cassiterite, pyrite and pyrrhotite bodies occur at Mount Bischoff, Mount Cleveland and Renison Bell. At Bischoff the host rocks are Upper Precambrian quartzite, shale and dolomite, cut by quartz-porphyry sills and dykes, in a cross folded anticline plunging west-southwest. Some cassiterite occurs in the dykes, some in veins and on joint faces near the intrusions, some in fissure lodes but most of it replacing dolomite in the form of sulphides and cassiterite. Cassiterite and sulphides occur as sheets concordant with the beds, and

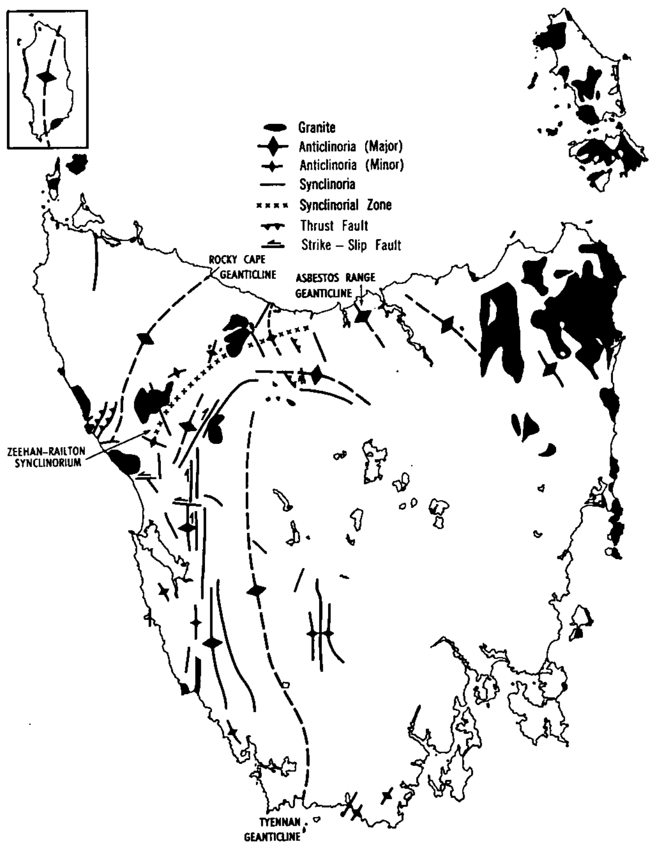


Figure 16 — Major Tabberabberan structures and intrusions.

as fissure lodes in Upper Precambrian and Cambrian sandstone, dolomite, conglomerate, chert and mudstone in a southeasterly plunging faulted anticline at Renison Bell. Greisenised quartz porphyry dykes are intruded near the hingeline of the folds. At Mt Cleveland cassiterite occurs in pyrite and pyrrhotite lenses replacing beds of Cambrian tuff and slate.

Argentiferous lead and zinc bodies occur in the Zeehan-Dundas Field, at Magnet near Waratah and at Round Mountain. In the Zeehan-Dundas area fissure veins, mainly with a north-northwesterly and north-northeasterly trend but some in intermediate directions, occupy faults, shears and fractures in Precambrian to Devonian rocks. A bifurcating vein occupying intersecting shears parallel and sub-parallel to the margins of an albite porphyrite dyke in pyroxenite intruding Cambrian sediments occurs at Magnet. Saddle reefs in ower Ordovician sandstone occur near the Dolcoath Granite t Round Mountain.

Granitic rocks at Renison Bell, Mt Bischoff and Dolcoath ave tin deposits close to them and zinc-lead deposits at eehan and Dundas, Magnet and Round Mountain as more istant haloes.

Deposits not related to Granite: Gold, zinc, lead and copper ccur in several areas not closely associated with granitic ocks. Faulted gold-quartz reefs occur at Beaconsfield in ower Ordovician sandstone and associated rocks. The Iathinna Beds contain gold near Lefroy in quartz veins ending 80°, arranged *en echelon* in a north-northwesterly irection, and cut by faults. At Mathinna gold occurs in uartz veins along and on the side of a zone of close folding ending north-northwesterly in Mathinna Beds.

Sulphides occur associated with Cambrian volcanic rocks t Chester, Mt Farrell, near Rosebery and at Mt Lyell. At hester, pyrite occurs in steep lenses in quartz sericite schist. alena and sphalerite at Mt Farrell occupy north-northwest-rly trending fissure lodes in a north-northeasterly trending elt of Cambrian shale and tuff in the Mt Read Volcanics. teep easterly dipping, *en echelon* lenses of galena, sphalerite, nd chalcopyrite occur in sericite schist overlain by dark rey shale under the Mt Read Volcanics in the Rosebery and Villiamsford areas. These lenses are controlled by the leavage. At Mt Lyell chalcopyrite, bornite and pyrite ccur disseminated in a meridional strip in schisted Cambrian olcanic rocks close to their contact with the Owen Con-lomerate. The ore deposits were formed subsequent to the olding and were controlled by the meridional Great Lyell ault Zone and the west-northwest trending Linda Fault one. The schistosity controlled the ore deposition on a ninor scale.

PERMIAN

Ice flowing from an area west of Tasmania covered the tate during part of Upper Carboniferous and early Permian me. This ice rested on a surface with a relief of 3,000 feet, vith a high area near Cradle Mountain and along the present osition of the east coast highlands. A fjord was probably resent near Wynyard.

Early in the Permian the ice retreated leaving remnants f ice on high areas such as the promontory near Cradle Iountain and on the "East Coast Peninsula". A gulf, otted with islands particularly in its northern part, developed etween the high areas. This gulf slowly filled with car-onaceous pyritic siltstone containing glendonites and an orizon of algal oil shale. These silts contain fossils, partic-larly polyzoa and brachiopods. Icebergs of westerly origin ropped erratics into the silt. The sea became shallower nd richly fossiliferous limestone was deposited. especially ear the shore of the "East Coast Peninsula". Further west ery fossiliferous polyzoal siltstone formed. *Eurydesma* ourished during formation of the limestone. These richly ossiliferous beds pass up into siltstone with decreasing umbers of fossils as the water of the gulf became brackish nd deltas advanced into the sea, possibly due to uplift of the nd. Deposition of quartz sandstones and siltstones and arbonaceous siltstones, coal and cannel coals occurred on ne coastal plains behind the deltas. On these plains *Glossop-eris*, *Gangamopteris*, *Noeggerathiopsis* and other plants flour-hed. The sea advanced over the plains once to form narrow north-northwesterly trending gulf then retreated, nd the same types of sediments were deposited on the coastal lain as on the earlier coastal plain. Later the sea advanced ver the coastal plain and the fringing highlands, depositing ossiliferous siltstone and limestone containing erratics. 'hese rocks were richly fossiliferous, containing an abund-nce of polyzoa, brachiopods, crinoids, pelecypods, gas-eropods and other fossils. The rich benthonic fauna was killed a little later as sand-laden currents from shallow water close to the rejuvenated highlands to the northwest and northeast spread sand and pebbles over the sea floor. The sands were overlain by unfossiliferous siltstone containing a few erratics, and then by siltstone containing an abundance of brachiopods, pelecypods and polyzoa, the result of recolo-nization of the areas previously swamped by sand and pebbles. Further sand-laden currents deposited more sand and again killed the benthonic fauna. Later, poorly fossilifer-ous silts, with two further incursions of sands, were deposited. During deposition of these silts the axis of the trough of deposition moved westward. Deposition of freshwater quartz sands, silts and carbonaceous silt and coal followed, disconformably on the marine sediments in some places. Some uplift of an area near Cradle Mountain occurred. The Permian sediments totalling only about 2,500 feet thick, were deposited in an unstable shelf environment in frigid to cool temperate seas.

The Permian System shows gentle dome and basin struc-ture superimposed on a major syncline plunging to the southeast.

TRIASSIC

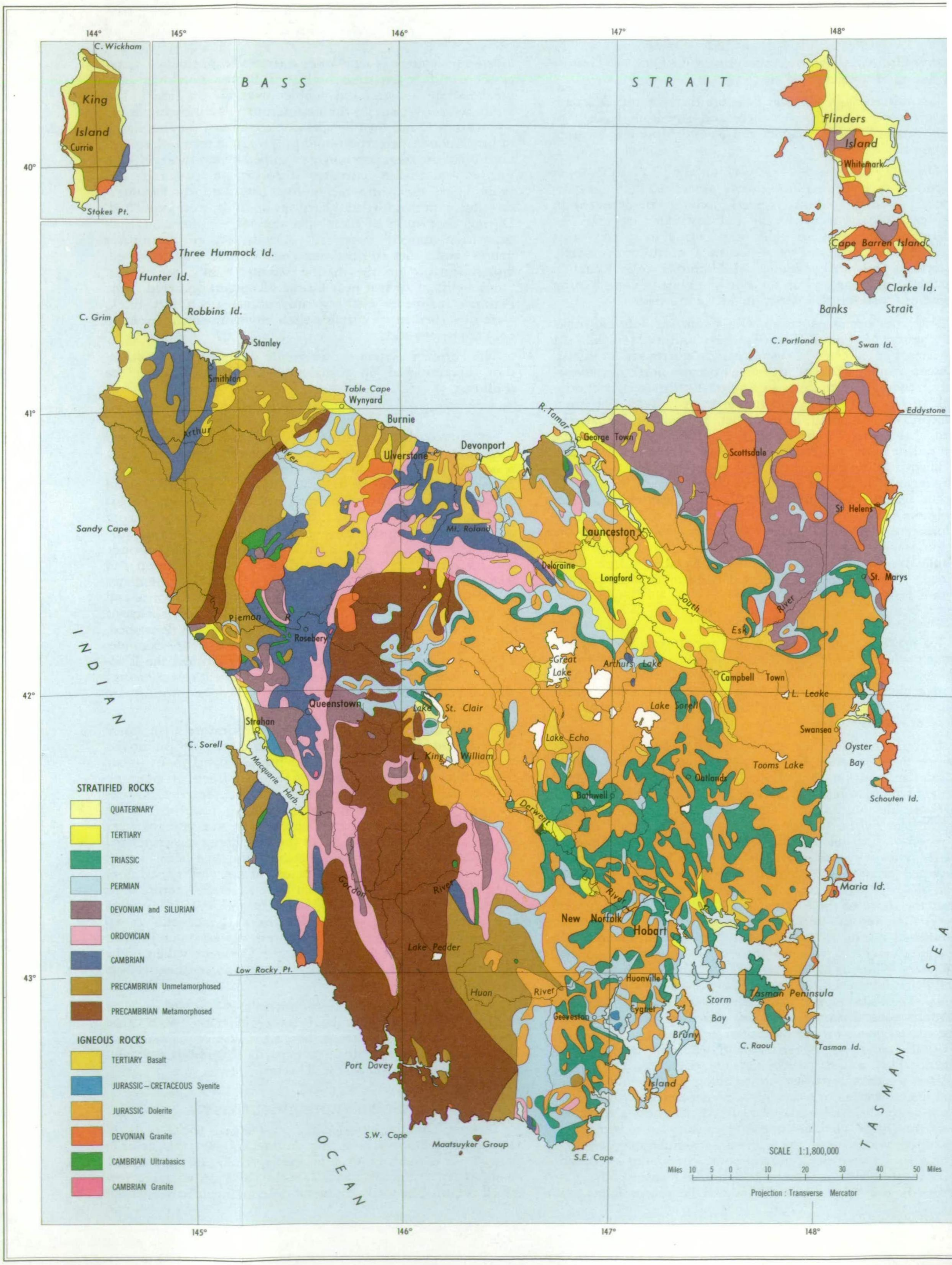
Sands and silts, consisting predominantly of quartz, and some granule and pebble gravels probably derived from a zone of hills trending south-southeasterly from Cradle Mountain and higher to the north than to the south, spread over a lowland area, now the midlands and southeast. Cross-bedding and slump structures indicate currents flowing mainly from the northwest over a southeasterly sloping sur-face. The sand, silt and gravel accumulated in lakes, ponds and river channels. Erosion and redeposition of pond and lake silts suring floods produced clay pellet conglomerates containing disarticulated amphibian and reptilian bones and lung fish teeth. More complete reptilian and fish skeletons occur in the siltstone. During this time equisetales flourished, and ferns such as *Cladophlebis*, seedferns (for example, *Dicroidium*), conifers, ginkgoes and cycads clothed the land-scape. These lower beds, up to 1,300 feet thick, rest conform-ably, disconformably and with slight angular unconformity on Permian rocks.

As the hilly country was eroded, silts rather than sands were deposited and the western limit of silt deposition moved westward. The quartzose sediments are overlain by more feldspathic sandstones about 650 feet thick, containing appreciable quantities of chlorite and rock fragments, pre-dominantly volcanic but including Permian mudstone. These sandstones may be partly tuffaceous and are perhaps very largely redistributed tuffs. With the sandstones are associated carbonaceous claystones and siltstones and coal beds formed in swamps and lakes. An abundant but not very varied flora flourished. It included liverworts, equisetales, ferns, seed ferns, ginkgoes, *Phoenicopsis*, conifers and cycads. Insects were present. Spores show that the coal measures at St. Marys are Rhaetic and a seed fern indicates a Lower Jurassic age for the coal at Hamilton in the Derwent valley. The climate during the Upper Triassic and Lower Jurassic was cool and humid.

The Lake St. Clair-Cradle Mountain area was uplifted late in the Permian or early in the Triassic. Later the "East Coast Peninsula" was rejuvenated, became a source of sediment during the Upper Triassic but was partly covered by sediment again at least as early as the Rhaetic.

MESOZOIC IGNEOUS ACTIVITY

Dolerite: Dolerite intruded the pre-Permian rocks as dykes and pipes. On reaching the Permian rocks the dolerite spread out in the form of cone-sheets, sheets, sills and dykes, which cut the Permian and Triassic. Sills up to 1,400 feet thick occur. The total volume of dolerite intruded was about


144°
145°
146°
147°
148°
40°
41°
42°
43°
C. Wickham
King Island
Currie
Stokes Pt.
BASS STRAIT
Flinders Island
Whitemark
Cape Barren Island
Clarke Id.
Banks Strait
Three Hummock Id.
Hunter Id.
Robbins Id.
C. Grim
Stanley
Smithton
Arthur
Table Cape
Wynyard
Burnie
Ulverstone
Devonport
R. Tamar
George Town
C. Portland
Swan Id.
Eddystone
Scottsdale
St Helens
River
Sandy Cape
Mt. Roland
Launceston
Deloraine
Longford
South
Esk
St. Marys
Piemon R.
Rosebery
Great Lake
Arthurs Lake
Campbell Town
L. Leake
INDIAN
Queenstown
Lake St. Clair
Lake Sorell
Swansea
Strahan
C. Sorell
Lake Echo
Oyster Bay
L. King William
Tooms Lake
Macquarie Harb.
Oatlands
Bothwell
Schouten Id.
Derwent
Gordon
River
Maria Id.
New Norfolk
Hobart
Lake Pedder
Low Rocky Pt.
Huon
River
Huonville
Tasman Peninsula
Storm Bay
Geeveston
Cygnet
Bruny Island
C. Raoul
Tasman Id.
Port Davey
S.W. Cape
Maatsuyker Group
S.E. Cape
OCEAN
TASMAN SEA
STRATIFIED ROCKS
QUATERNARY
TERTIARY
TRIASSIC
PERMIAN
DEVONIAN and SILURIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN Unmetamorphosed
PRECAMBRIAN Metamorphosed
IGNEOUS ROCKS
TERTIARY Basalt
JURASSIC–CRETACEOUS Syenite
JURASSIC Dolerite
DEVONIAN Granite
CAMBRIAN Ultrabasics
CAMBRIAN Granite
SCALE 1:1,800,000
Miles 10 5 0 10 20 30 40 50 Miles
Projection: Transverse Mercator

,000 cubic miles. The dolerite is a differentiated tholeiitic uartz dolerite with pegmatitic and granophyric differentiates.)ifferentiation took place by fractional crystallization nd relative movement of the phases under gravity. The olerite produced little contact metamorphism except f Permian limestone and calcareous shale from which alcsilicate rocks were produced. Intrusion of the dolerite ook place as a single event (except for minor late phase ntrusions) about 165 million years ago in the lower part of he Middle Jurassic Epoch. The intrusion was associated vith tensional faulting.

Syenite: Alkaline porphyries and syenite occur as a stock ssociated with a radial dyke swarm near Cygnet in southastern Tasmania. These rocks intrude dolerite but are older han 100 million years. They are associated with minor gold nineralization.

CAINOZOIC

Late in the Mesozoic or early in the Tertiary normal aulting with a north-northwesterly trend produced major rabens with horst and graben or step fault structure. Three f these grabens appear to converge on Storm Bay (Figure 7). The grabens occupy the major down-warped areas in he Permian and Triassic sediments, and resulted from ension in an east-northeasterly direction.

In the grabens silts, sands, clays, gravels and lignite were eposited during the Palaeogene and Neogene under lacustine, fluvial and paludal conditions. Fossil soils have been ecognised in the succession and laterites and bauxite are resent below and on top of the succession. The succession ; up to 1,000 feet thick and is cyclic in some sections: i.e., ravel rests on eroded clays or silts, and is followed by sand, ilt, clay and lignite. These cycles probably represent repeated plift of the source areas along faults. The sediments contain bundant fossil remains of native pines, trees with broad hin leaves, cycads, fungi, ferns, casuarinas, banksias and other rees, and, in the Neogene, eucalypts and wattles. The egetation shows a warmer climate through most of the 'ertiary than that at present affecting Tasmania. Rain forest eems to have been present. Alluvial tin occurs in some of he non-marine sediments in sub-basaltic deep leads in the ortheast and is associated with gold.

Around the margin of Bass Strait and along the western oast of Tasmania almost as far south as Zeehan, marine alcarenites show an incursion of the sea beginning in the Jpper Oligocene, reaching a maximum in the Middle Miocene nd then decreasing. The sea advanced on Flinders Island gain late in the Pliocene. The calcarenites are dominantly olyzoan and molluscan but foraminifera including *Lepidoyclina* are also present in abundance. The marine beds also ontain fossilised whales, mollusc-eating sharks and a possum keleton.

Saturated and unsaturated olivine basalt flowed from ecks, mainly situated close to fault junctions. The necks re lava-filled, breccia-filled or are volcanic complexes conaining folded lavas and pyroclastic rocks. Extensive lava elds are found in northwestern Tasmania. The flows which eached a maximum aggregate thickness of 1,200 feet lled valleys cut in early Tertiary non-marine sediments and 1 the Oligocene-Miocene marine sediments. The basalt aused lateral displacement and twinning of pre-existing treams. Some pre-Upper Oligocene basalts have been ecognised but most basalts are later than Middle Miocene.

Faulting occurred in the late Tertiary and Quaternary and few earth tremors still occur. During the Quaternary, lluvial deposits have formed on valley floors, aeolian depsits around the coastline and in some low areas inland. Gold, tin and osmiridium have been concentrated in some f the alluvial deposits. During the Upper Pleistocene and ossibly earlier, ice covered the central highlands and plateau nd spread south, north and west along river valleys, and occurred on mountain peaks and in the higher valleys in other parts of Tasmania. Bass Strait was open during the Miocene, probably closed during part of the Pliocene, and open at some stages, closed at others, during the Pleistocene. When Bass Strait was closed Tasmania was connected with Victoria by an eastern ridge extending from Flinders Island to Wilsons Promontory, which probably provided the path by which the giant marsupials, *Nototherium* and *Diprotodon*, reached Tasmania and King Island respectively.

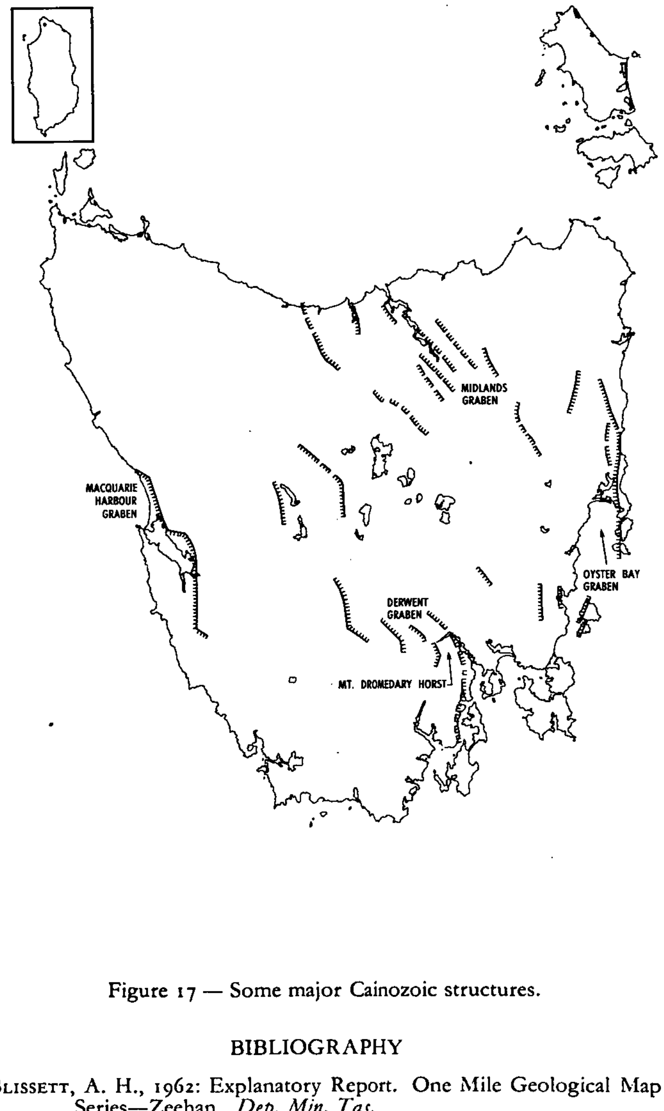


Figure 17 — Some major Cainozoic structures.

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.USTRALIA–TASMANIA

Tasmania is a rugged, triangular island of 8,000 km^2 (26,215 sq mi), with a relief up to 600 m. It is a southerly projection of the astern Australian mountain belt and is sepaated from the mainland by Bass Strait. The trait is a basin 90 m deep which is underlain by ontinental material. The King Island Rise and ie Tail Bank are on the W and the Bassian Rise on the E. Downwarping of the Bass Strait ea began possibly in the Triassic and connued at an increasing rate during the Upper retaceous and Tertiary. Bass Strait was closed times (eustatically) during the Pleistocene. he east and west coasts of Tasmania are faultontrolled.

listory of Geological Work

Coal was discovered in Tasmania in 1793 by rench scientists during the D'Entrecasteaux xpedition. A. W. Humphrey was official minralogist to the state from 1804 to 1812. Later, ie island was visited by such prominent eologists as Darwin, Jukes, and Strzelecki beveen 1830 and 1845. Local geological work egan with J. Milligan's (1849) study of the oal resources and with the work by A. R. C. elwyn on Tasmanian oil shales and coals in the 850s. Gold was discovered in 1852, followed y the visit of W. B. Clarke in 1855, and this d to the appointment of Charles Gould as eological surveyor between 1859 and 1869. in was discovered at Mt. Bischoff in 1871, and iis was followed by the discovery of zinc, lead, nd copper at Rosebery and Mt. Lyell. R. M. ohnston worked as an amateur geologist in asmania between 1870 and 1919. His *Geology f Tasmania* (1888) is classic and is the first easonably comprehensive statement on the eology. The Geological Survey was initiated ith W. H. Twelvetrees in charge in 1899. After 918, Loftus Hills began underground water, oal, and oil shale surveys. Later the survey was ss active, until 1954, when J. E. Symons was opointed as Director of Mines and regional irveys were begun at a scale of 1 inch to the iile, with an active research program. From 1922 to 1946, A. N. Lewis, an amateur geologist, made significant contributions to the knowledge of Pleistocene glaciation and the Permian and Ordovician stratigraphy of Tasmania.

At the turn of the century, the Zeehan School of Mines taught geology as part of their courses in metallurgy. Geology was taught at the University of Tasmania from 1899 to 1915 and sporadically from 1926 until 1936. The department of geology was instituted in 1946 under S. W. Carey. Research initially concentrated on regional mapping and geotectonics.

Geological History

Precambrian. Silts, sands, conglomerates, and dolerite intrusions of the olivine basalt suite total 6000 m and represent the oldest sequence (Fig. 1). Quartzites, phyllites, and slates, deformed conglomerates, and amphibolites with eclogitic nodules have been metamorphosed to the greenschist facies. They were affected late in the Precambrian by the "Frenchman Orogeny," which occurred in two phases. Basic dikes with concentrations of magnetite were intruded between the phases. The folds and a NNE-trending geanticline are probably related to the second orogenic phase.

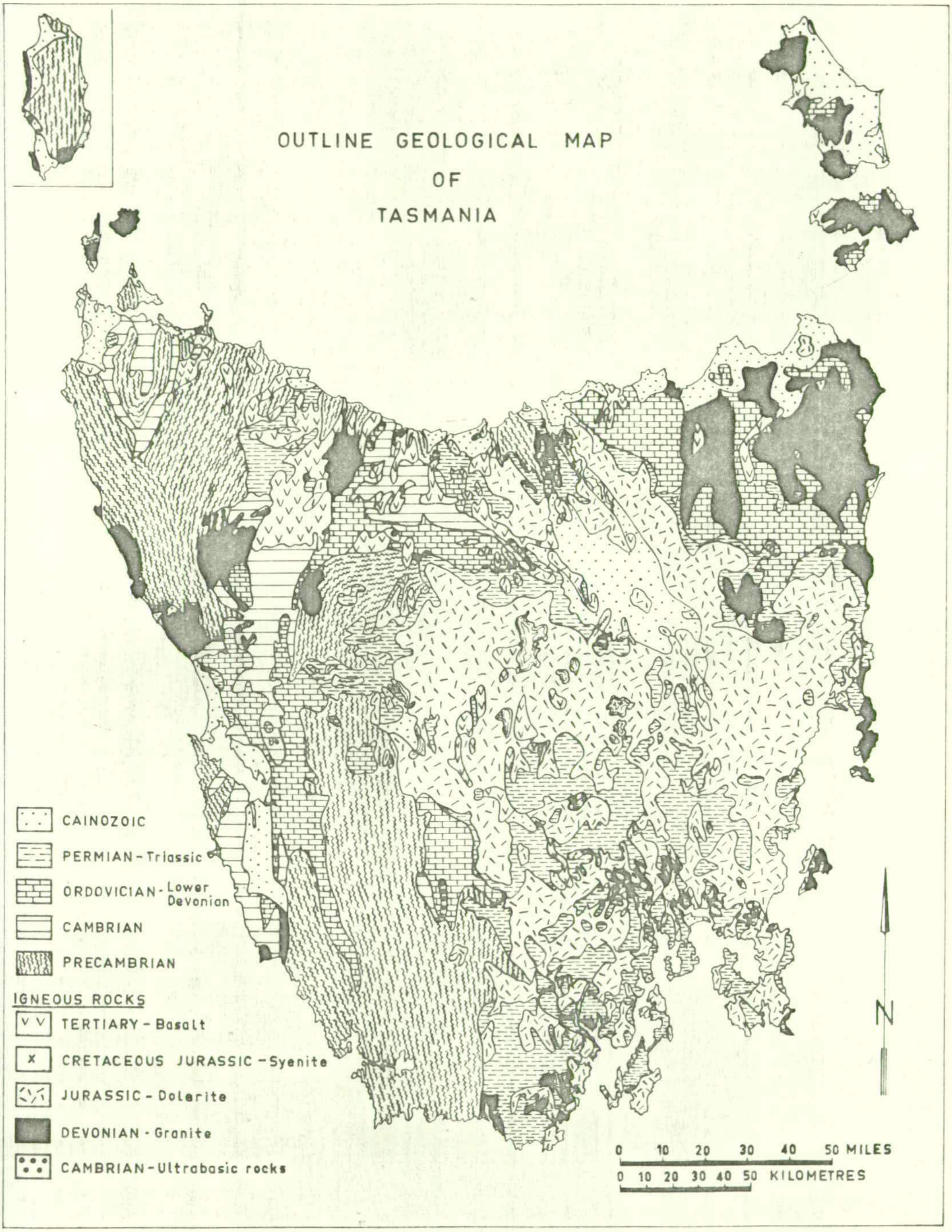
On both sides of this geanticline, quartzite, slate, and phyllites, some conglomerate, and dolomite with basalt and tuff are 4500 m thick. These rocks were gently folded during the "Penguin Movement." Intrusion of dolerite sills and dikes, one of which has been dated at 700 m yr, occurred before and after the folding.

Following the Penguin Movement, a long interval of erosion was succeeded by gentle downwarping along a NNW-trend, with deposition in shallow water of oolitic limestones and dolomites and a small proportion of clastic sediments such as silt and sand. The dolomitic sequence reached a thickness of 1200 m, and a low source area is indicated during its formation. Deposition of the dolomites was followed by uplift of a meridional ridge, the Tyennan Geanticline.

Cambrian. Cambrian rocks rest unconformably on the metamorphosed Precambrian but conformably on the dolomitic sequence west of the Tyennan Geanticline, where there was a change in the type of sedimentation and in the rate of sinking. The first deposits were mainly siltstones, with thin graywackes, dolomitic siltstones, polymict conglomerates, chert, and minor spilitic and keratophyric lavas and tuffs, totaling 3000 m.

This succession is overlain by fossiliferous Middle and Upper Cambrian siltstones, gray-

FIGURE 1. Outline geological map of Tasmania.



wackes, paraconglomerates, some limestone and dolomite beds, acid and basic lavas, and tuffs. These sediments show cyclic deposition, indicating intermittent uplift of the source areas, but in general they become coarser upward. Mostly acid lavas and pyroclastic rocks, totaling 3000 m and belonging to the spilite suite, occur in an arc bordering the geanticline on the west, north, and east.

Movements during deposition are shown by unconformities in the Middle Cambrian and at the base of the Upper Cambrian. A marine rough with some islands surrounded the Tyen-ıan Geanticline during the Middle and Upper Cambrian. Trilobites, brachiopods, gastropods, ponges, and graptolites comprise the fauna.

Serpentinite derived from pyroxenite and other ultrabasic and basic rocks, intruded as concordant sills, as slightly discordant sheets, or as dikes into the Cambrian sequence. These ntrusions generally were close to the Pre-cambrian-Cambrian boundary on the eastern side of uplifted areas and form two roughly meridional belts 50–80 km apart. They contain segregations of osmiridium and other heavy metals and copper and nickel sulfides. Osmirid-um occurs also in a Lower Franconian beach placer deposit. Several small concordant gran-tic intrusions into the core of the Mount Read arc volcanic pile were emplaced before the Or-dovician.

Late in the Cambrian, rejuvenation of the Tyennan Geanticline during the "Jukesian Movement" produced a zone of tight folding near the geanticline and gentle folding else-where.

Ordovician. Local fanglomerates up to 420 m thick, developed from volcanic and other rocks, flank the Tyennan Geanticline. Later, alluvial fans of siliceous gravel and sand up to 720 m thick and derived from the Precambrian rocks of the Tyennan, Rocky Cape, and Asbes-tos Range geanticlines spread over the lowlands. Early in the Ordovician, some faulting occurred close to the margins of the Tyennan Geanti-cline. As the geanticlines eroded, the sea en-croached and up to 300 m of shallow-water sand was deposited, passing up and toward south-central Tasmania into fossiliferous silt-stone 300 m thick. The sandstones and siltstones contain Middle and Upper Arenigian trilobites, graptolites, and other fossils. With further erosion of the source area and further transgression of the shallow sea, limestone up to 1500 m in thickness covered much of Tas-mania. The base of this limestone is Upper Canadian, the top Cincinnatian; and it is over-lain by an Upper Ordovician siltstone about 50 m thick. Deposition of the sandstone, silt-stone, and limestone occurred on a slowly sink-ing shelf in a warm sea. These shelf sediments pass eastward into siltstone with thin sandstone bands and contain rare Lower Ordovician grap-tolites.

Silurian and Devonian. In the late Ordo-vician or early Silurian uplift in northwestern Tasmania and faulting in northern Tasmania initiated a period of instability ending in the Middle Devonian. In western Tasmania, 800 m of pebbly sand and sand was deposited, fol-lowed by alternating units of sandstone and siltstone with some coralline limestone. The fauna consists predominantly of brachiopods and trilobites, but Lower Llandoverian, Wen-lockian, and Lower Ludlovian graptolites occur. These shelf sediments pass NE and E into geo-synclinal turbidites. They contain a few fossils (Lower Devonian graptolites) and are at least 1800 m thick. In southwestern Tasmania, a basin formed in the Lower Devonian in which accumulated 640 m of shallow-water conglom-erate, sandstone and siltstone, and coralline limestone.

Devonian Orogeny (Table 1). There were two main phases of Devonian orogenic activity: the first formed long folds parallel to the mar-gins of the geanticlines; the second created NNW-trending minor folds which were later cut by thrust and wrench faults. The Ordovician-Lower Devonian geosynclinal beds of northeast-ern Tasmania were folded into anticlinoria and synclinoria, while the Cambrian to Lower Devo-nian deposits to the W were faulted, the com-pression being from the east-northeast.

Following the orogeny, Upper Devonian to Lower Carboniferous alkaline to calcalkaline plutonic rocks were intruded along zones of inflection between major anticlinoria and syn-clinoria. The intrusions were often multiple, composed mainly of adamellite but with some basic differentiates.

Underground (karst) drainage developed in northern Tasmania after the folding, and Upper Devonian cave deposits were formed; these re-main unfolded.

Permian. A hiatus occurs following the De-vonian orogeny. During the Upper Carbonif-erous a large ice sheet extended from the W to cover all of Tasmania. The retreating ice formed a promontory in Cradle Mountain and a penin-sula in the east coast separated by an island-dotted gulf. In the gulf, carbonaceous pyritic siltstone containing algal oil shale, glendonites, and iceberg-rafted erratics were deposited dur-ing the early Sakmarian. These beds coarsen up-ward and to the E. They are overlain by richly fossiliferous siltstone and limestone that con-tains bryozoans and large numbers of *Eurydes-ma.* The limestone is overlain by less fossilifer-ous siltstone deposited in shallow and possibly brackish water. Early in the Artinskian in northwestern Tasmania, well-sorted sand, silt, and coal were deposited on the coastal plains behind advancing deltas. *Glossopteris, Ganga-mopteris,* and *Noeggerathiopsis* were abundant. The sea advanced briefly over this coastal plain and formed a NNW-trending gulf in central and southern Tasmania. Later, in the Artinskian, the sea transgressed the plains and the highland areas and deposited richly fossiliferous siltstone and limestone together with ice-rafted erratics. Productids and bryozoans were the main fossils,

TABLE 1. Stratigraphic Table for Tasmania

Period (and Epoch)	Rock Types	Thickness (meters)	Fossils	Igneous Activity	Tectonism	Economic Deposits	Other Features
Quaternary Holocene	Alluvium; dunes; beaches etc.				Normal faulting		
Pleistocene	High-level beaches; swamp, lake deposits; alluvium in terraces; fossil dunes; till; rhythmites		*Euryzygoma*, *Thylacoleo*, *Acacia*		Normal faulting; some uplift	Alluvial tin, gold, osmiridium	Glaciation (at least two eposides)
Tertiary Pliocene				Basaltic vulcanism	Some uplift	Very minor bauxite	Warm, humid climate Disconformity
Miocene and U. Oligocene	Bryozoal calcarenites and	80	*Trybliolepidina*, *Wynyardia*	Basaltic vulcanism			
	fluviatile and paludal deposits	≃100	Coniferous and broad-leafed dicotyledonous flora			Some alluvial tin	
Paleogene	Fluviatile and paludal deposits	≃300	Coniferous and broad-leafed dicotyledonous flora	Basaltic vulcanism			Warm, humid climate
	angular unconformity				Tensional faulting		
Cretaceous Upper Cretaceous and Paleogene	Laterite and bauxite	≃10				Minor bauxite	Warm, humid climate
Middle Cretaceous	Syenitic rocks			Syenitic stocks and dikes		Minor gold	95 m yr (K/Ar age)
?Cretaceous				Appinitic intrusions and flows			
Jurassic Middle Jurassic	Dolerite			Sheets, sills, dikes	Tensional faulting		165 m yr (K/Ar age)

Triassic	Coal; lithic arenites; claystones; quartz sandstone, siltstone	1000	*Cladophlebis, Dicroidium, Phoenicopsis, Pachypteris* (cycads); *Blinasaurus* (reptile)	?Andesitic tuffs	Gentle downwarping	Coal *brick "clays"*	Humid climate *(?cold)*; monsoonal climate
					?Gentle warping		
	conformity to low-angle angular unconformity						
Permian	Pebbly siltstone; sandstone; conglomerate; tillite; limestone; coal; oil shale	800	*Taeniothacrus, Martiniopsis, Wyndhamia, Stenopora, Eurydesma, Glossopteris, Tasmanites*	?Ash bed Metabentonite	Gentle down warping with some broad, low-amplitude upwarps	Subeconomic coal, oil shale, limestone	Two major cycles of shallow marine and nonmarine sediments; cyclothems; glacial influence from late Carboniferous to late Permian
Upper Carboniferous	Tillite, rhythmites	>600	*"Rhacopteris," Tasmanadia*				
Lower Carboniferous to Upper Devonian	nonconformity or angular unconformity Granite rocks			Batholiths, stocks, sheets, dikes		Gold, tin, tungsten, lead-zinc, copper deposits	Granite rocks younging westward 365 to 340 m yr (K/Ar ages)
Middle Devonian	Cave deposits		*Radiospora*				Post-orogenic
	angular unconformity				Some folding in Lower Devonian		
Lower Devonian to Lower Silurian	Siltstone; sandstone; rare limestone	≃1500	*Martinophyllum, Squameofavosites, Australocoelia, Pleurodictyum, Notoconchidium, Monograptus, aequabile* and spp., *Cyrtograptus, Rostricellula*				Major sandstone-siltstone alternation; shelf deposits passing east to slope deposits
	?disconformity						

(table continues on next page)

Period (and Epoch)	Rock Types	Thick-ness (meters)	Fossils	Igneous Activity	Tectonism	Economic Deposits	Other Features
Ordovician to Upper Cambrian	Limestone, siltstone, sandstone, conglomerate	≃2000	*Ningkianolithus, Palaeophyllum, Tetradium, Foerstephyllum, Lichenaria, Maclurites, Manchuroceras, Asaphopsis, Carolinites, Didymograptus, Clonograptus, Proceratopyge*		Local faulting in Lower Ordovician and Upper Cambrian	Limestone Fossil placer deposits with osmiridium	?Disconformity; Cambrian marine siltstones pass up into sandstone, overlain by fanglomerate; this followed by marine L. Ordovician sandstone, siltstone and by M-U Ordovician shelly limestone; in Ordovician shelf deposits pass east to slope deposits
Upper and Middle Cambrian	Siltstone; lithic wacke and conglomerate; chert; rare limestone; acid, intermediate and basic volcanic rocks, including ignimbrites; ultrabasic rocks; serpentinites; rare granites		*Glyptagnostus, Ptychagnostus, Lejopyge, Centropleura, Nepea,* sponges, dendroids	Granite stocks; ultrabasic complexes, sheets, sills, dikes, flows, including pillow lavas; ash beds; keratophyric and spilitic	Some folding and faulting	Copper deposits; zinc-lead	"Eugeosynclinal" association
Pre-Middle Cambrian	Diamictite quartzite, slate, dolomite	3000		Basic dikes and sills	Folding Folding and metamorphism		?Glaciation 700 m yr (K/Ar age)
	Quartzites; phyllites; schists, including garnetiferous schists; eclogites; amphibolites; dolomite	≫6000		Amphibolite sheets, eclogite masses		Magnetite deposits	

but the limestone is also rich in crinoids and has a few corals such as *Euryphyllum*. The fauna is distinctly Western Australian. Early in the Kungurian, the highlands emerged from the sea. Deposition of sand and pebbles was followed by silt, but further uplift late in the Kungurian or early in the Kazanian caused the succeeding siltstones to be poorly fossiliferous. Late in the Permian, probably in the Tatarian, areas in western and northeastern Tasmania were uplifted and freshwater sands, silts, and coal with *Glossopteris* and *Vertebraria* were deposited on a flood plain.

The Permian rocks of Tasmania are only 750 m thick and were deposited on an unstable shelf in a frigid to cool temperate zone. The Permian now has gentle dome and basin structure superimposed on a SSE-plunging major syncline.

Triassic. The Triassic rests conformably, locally unconformably, on the Permian rocks and consists of nonmarine quartz sandstone, siltstone, and granule conglomerate up to 400 m thick. These rocks are cross-bedded and contain vertebrates, particularly amphibians, some fish and reptiles, and many plants, including equisetales, *Dicroidium*, and *Cladophlebis*. These rocks were overlain by 200 m of lithic arenite with chlorite, feldspar, and volcanic fragments as well as pieces of Permian mudstone. The lithic arenite is found with carbonaceous claystone and coal and is tuffaceous in places. Liverworts, ferns, seed ferns, cycads, and other plants flourished, showing that these Rhaetic beds formed in a cool humid climate. The Triassic rocks now form a major SSE-plunging syncline.

Igneous Activity (Fig. 2). Early in the Middle Jurassic, about 8000 km^3 of tholeiitic quartz dolerite intruded the pre-Permian rocks as pipes and dikes and cut the Permian and Triassic rocks as conesheets, sheets, sills, and dikes. These intrusions attained thicknesses of 400 m. Associated with the dolerites are granophyric and pegmatitic differentiates.

An alkaline syenite body with radial dike swarms intruded Jurassic dolerite and Permian sediments in southeastern Tasmania. The stock is associated with small gold deposits and gives a radiometric age of 100 m yr.

Tertiary. Late in the Mesozoic or early in the Tertiary NNW-trending normal faults developed horsts and grabens.

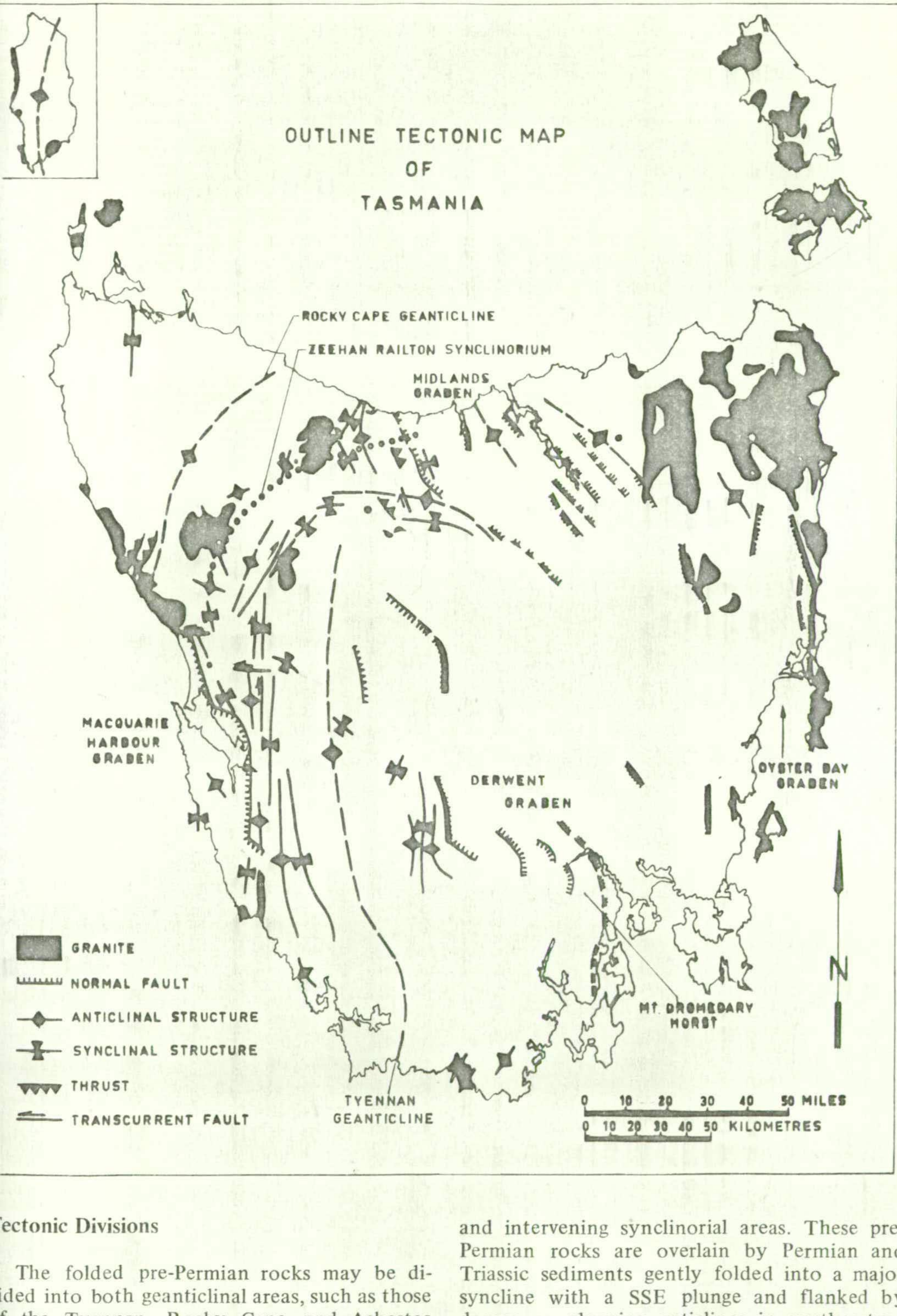
In the grabens, lacustrine, fluvial, and palustrine silts, sands, clays, gravels, and lignite were deposited during the Paleogene. These nonmarine sediments are up to 275 m thick and show asymmetrical cyclic sedimentation, probably representing repeated uplift of the source areas along faults. The sediments contain abundant plant fossils, remains of native pines, trees with broad thin leaves, cycads, fungi, ferns, casuarinas, banksias, and other trees. *Eucalyptus* and *Acacia* have been reported from Neogene nonmarine beds. Alluvial tin occurs in some of these nonmarine sediments in subbasaltic deep leads in northeastern Tasmania. Bauxite is present below and on top of the Tertiary nonmarine succession.

Around the margin of Bass Strait and along the western coast of Tasmania, almost as far S as Macquarie Harbour, marine calcarenites were deposited during an incursion of the sea beginning in the Upper Oligocene, reaching a maximum in the Middle Miocene, and then retreating. Readvance of the sea onto Flinders Island took place in the late Pliocene. The marine beds, only a few tens of meters thick, contain many invertebrate fossils as well as whales, sharks, and the skeleton of an opossum-like creature, the earliest known marsupial in this area.

Saturated and unsaturated olivine basalt, flowing from vents situated close to fault junctions, filled preexisting valleys to depths of 400 m. In places, the lava crossed valley divides and flowed into adjacent valleys, producing extensive lava fields. The valleys were cut in early Tertiary nonmarine sediments and in Oligocene-Miocene marine sediments. Some pre-Upper Oligocene basalts have been recognized, but most basalts are later than Middle Miocene.

Quaternary. Faulting occurred in the late Tertiary and Quaternary, and a few earth tremors still shake Tasmania. At times, during the Quaternary, alluvial deposits accumulated on valley floors, eolian deposits formed around the coastline, and glacial sediments were deposited on the highlands and in some valleys. Gold, tin, and osmiridium have been concentrated in some of the alluvial deposits. There is evidence of only one widespread Upper Pleistocene glacial phase, but there is scattered evidence of an earlier phase. During the principal phase, a highland icecap covered central Tasmania and spread N, W, and S as valley glaciers. Mountain glaciers occurred in southwest Tasmania, and valley glaciers were present in parts of south-central Tasmania. The glaciation is probably equivalent to the Wisconsin of North America. Pleistocene fluctuations in sea level are recorded as sea caves, inland cliffs, raised beaches, shore platforms, and as submerged river valleys. The fauna included some large extinct marsupials, such as *Nototherium* and *Diprotodon*, which probably reached Tasmania during a period of low sea level when the Bassian Rise formed a land bridge.

FIGURE 2. Outline tectonic map of Tasmania.



Tectonic Divisions

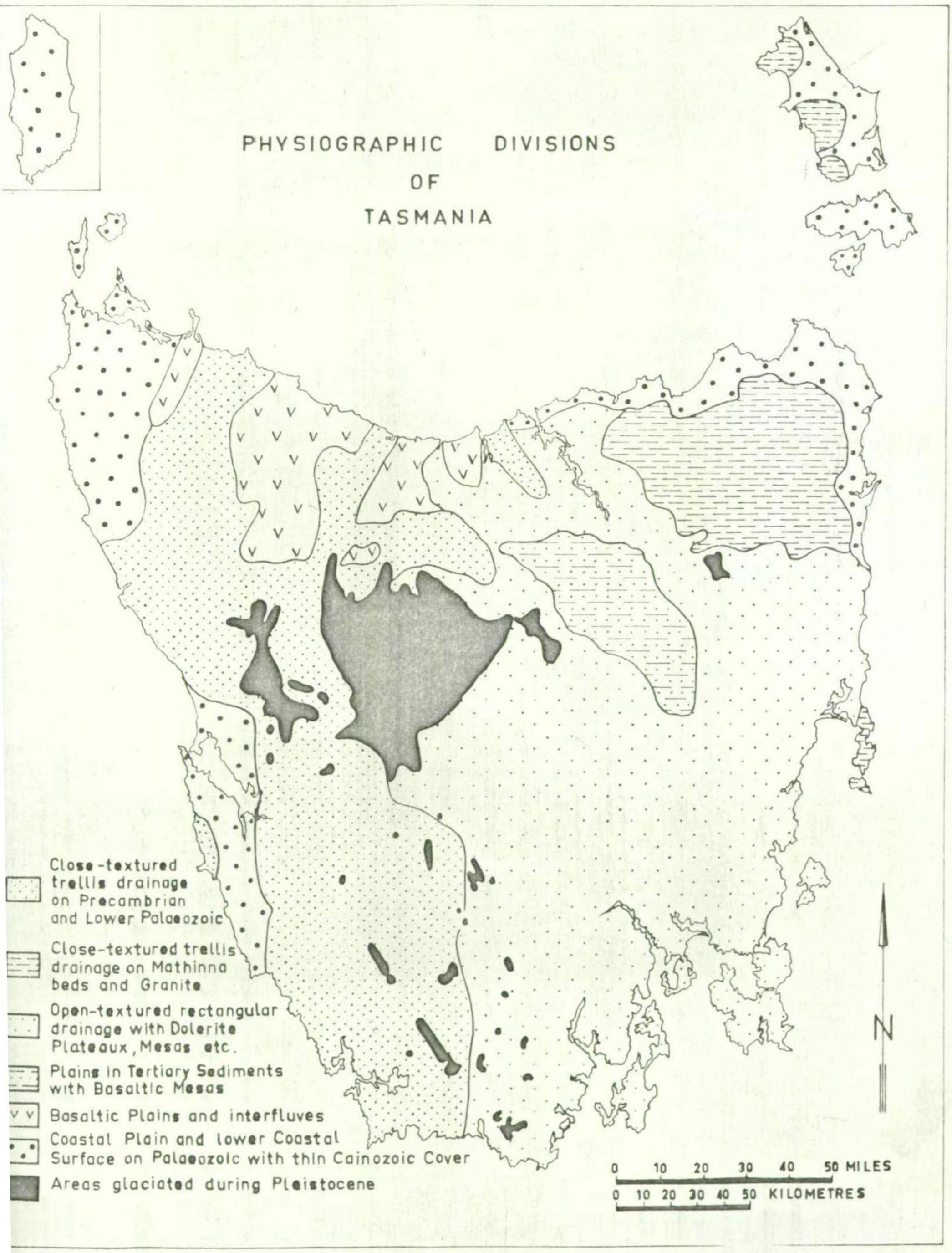
The folded pre-Permian rocks may be divided into both geanticlinal areas, such as those of the Tyennan, Rocky Cape, and Asbestos Range in which Precambrian rocks are exposed, and intervening synclinorial areas. These pre-Permian rocks are overlain by Permian and Triassic sediments gently folded into a major syncline with a SSE plunge and flanked by domes or plunging anticlines in northeastern and northwestern Tasmania. The Heemskirk

ticlinorium, trending NW just off the west
ast of Tasmania, was raised during the Devo-
an orogeny. Anticlinoria and synclinoria
derlie northeastern Tasmania. The synclinal
rmian and Triassic areas have been broken by
ults, forming large grabens.

Morphological Divisions

Two main types of land form can be recognized (Fig. 3). The folded pre-Permian rocks crop out as resistant quartzite and conglomerate strike ridges and streams following the

FIGURE 3. Physiographic divisions of Tasmania.



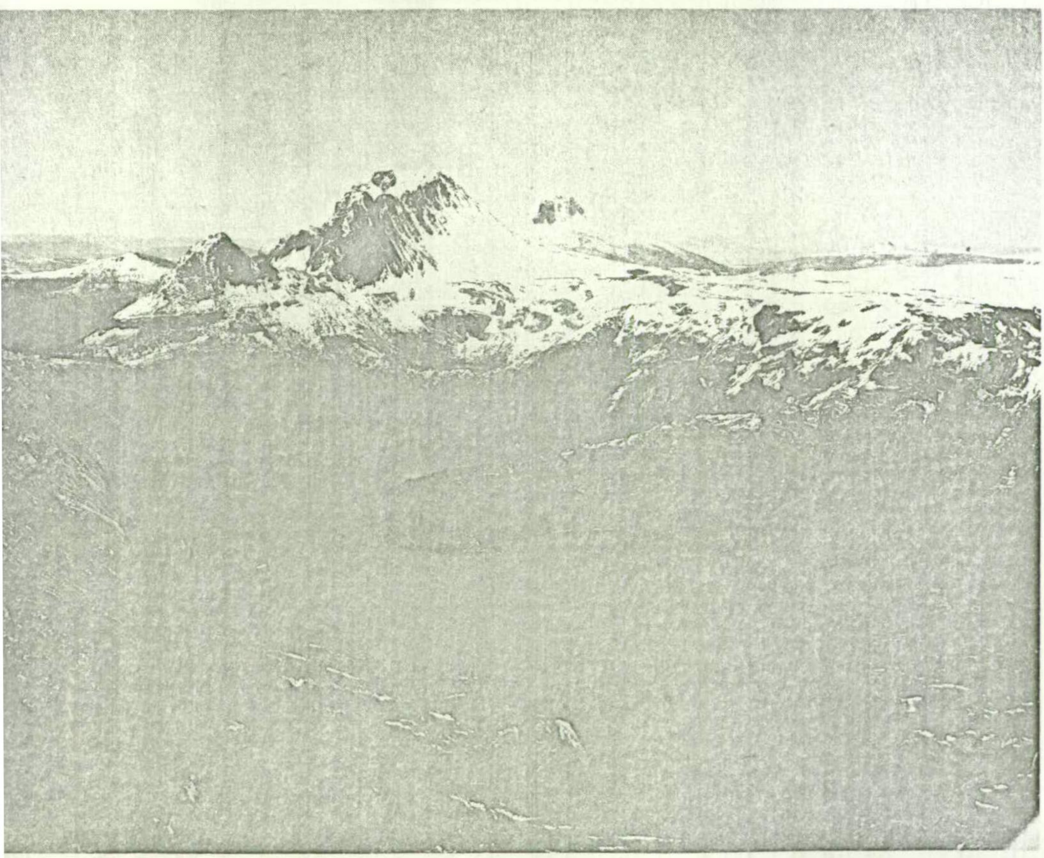
rike of softer shales, schists, and limestones ave a trellised drainage. In northeastern Tasiania, the rocks are more homogeneous and ie streams have a dendritic pattern with some inor joint control. The block-faulted, doleriteitruded, subhorizontal Permian and Triassic ediments of central and southeastern Tasmania ccur as tabular or plateau-like mountains, alost invariably capped by columnar dolerite nd flanked by dolerite scree (Fig. 4). In this rea the main drainage patterns are faultontrolled, and the minor streams follow a recingular pattern.

The island is in a youthful stage of physioraphic development. A series of accordant ·vels cut across both the folded pre-Permian ocks and the Permian and Triassic rocks at 190–1340 m, 900–1070 m, 730–820 m, 360–60 m, and 90–270 m. This suggests uplift of 10–670 m, probably since the Miocene. The oastline is deeply indented due to post-glacial ibmergence, but higher sea levels at 20 m, 15 m, 6 m (last interglacial), and approximately 0.8–1.8 m (Holocene) have been recognized.

Metallogenesis. Most of the economic metalliferous deposits of Tasmania are Devonian and occur in and around granite. Veins, dikes, pipes, and nodules of greisen with cassiterite or quartz, cassiterite, and tourmaline occur in granite in northeastern and western Tasmania. On King Island scheelite occurs in bands in Upper Precambrian contact metamorphic marble. Cassiterite-wolframite veins occur in a zone over a granitic cupola which intrudes Silurian-Devonian beds at Aberfoyle in northeastern Tasmania, and shallow-dipping veins occur also at nearby Storeys Creek.

Cassiterite and wolframite occur in the fissure veins of faults, along joints and bedding planes in Ordovician sandstone, and in impure limestone close to a granite at Moina in northcentral Tasmania. Cassiterite, pyrite, and pyrrhotite occur as fissure lodes, concordant sheets, and replacements in folded Upper Pre-

FIGURE 4. Monadnocks of subhorizontal glacigene Permian sediments intruded by Triassic dolerite sills and esting unconformably upon peneplaned Precambrian basement, Barn Bluff and Cradle Mt. Most of Tasmania as further glaciated during the Quaternary, the glaciers dissecting the former mature erosion surfaces and xcavating glacial valleys and lake depressions. [Photo (oblique air): "The Mercury", Hobart; by permission.]



ıbrian dolomites, sandstones, and shales in-
led by quartz porphyry dikes at Mount
:hoff and Renison Bell in western Tasmania.
siterite occurs in pyrite-pyrrhotite lenses
acing beds of Cambrian slate and tuff at
ınt Cleveland in northwestern Tasmania.
.ead, zinc, and silver occur as galena-
alerite bodies in fissure veins along faults in
:ambrian to Devonian rocks at Zeehan, in
ıs in a shear zone and in a porphyrite dike at
gnet near Mount Bischoff, and as saddle
's in Ordovician sandstone at Round Moun-
. in northern Tasmania.
Granites at Renison Bell, Mount Bischoff,
Dolcoath near Moina have a halo of tin
osits close to the granite, with zinc, lead,
silver deposits farther from the granite.
Gold-bearing quartz reefs occur in Ordo-
an sandstone at Beaconsfield in northern
mania and in the Silurian and Devonian geo-
clinal beds at Lefroy and Mathinna in north-
:ern Tasmania.
Galena and sphalerite occur as fissure lodes
shales and Cambrian tuffs at Mount Farrell
as a folded lens in a sericite schist overlain
dark gray shale beneath the Cambrian vol-
ics in western Tasmania. Chalcopyrite, bor-
:, and pyrite are disseminated in altered
nbrian volcanic rocks close to their contact
h Ordovician conglomerates in western Tas-
ıia. All these ore bodies are syngenetic or
y post-depositional, although there has also
n some later remobilization.

MAXWELL R. BANKS

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AUSTRALIA–VICTORIA

Victoria is the second smallest state in Australia, with an area of scarcely 130,000 km^2. European adventurers seeking new pastures for their sheep in 1834 were the first settlers in Victoria. When gold was found in 1851, the economics of the colony changed, and one result was the establishment of the Geological Survey of Victoria. The rapid growth of the population was a result of gold rushes and led to the severance of the new colony from New South Wales.

The thickest deposits of brown coal in the world are found in the Latrobe Valley in eastern Victoria; they provide briguettes and electricity, while hydroelectric power is generated in the mountains. Natural gas, first found offshore commercially in 1965, is piped to Melbourne, and a giant offshore oil province has been developed in Bass Strait which separates Tasmania from the mainland. It provides 60% of Australia's oil needs.

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WALLACE KIRSOP

GOULD, CHARLES (1834-1893), geological surveyor, was born on 4 June 1834 in England, son of John and Elizabeth Gould [qq.v.]. After graduating from the University of London (B.A., 1853), he won the duke of Cornwall's exhibition at the Royal School of Mines in 1854 and a Board of Trade certificate with many first-class passes in 1856. He then travelled with his father in eastern North America early in 1857, worked with the Geological Survey of Great Britain and left for Hobart Town on 12 April 1859. His initial contract at £600 a year with travelling expenses was to make a geological survey and prepare a book on the geology of Tasmania. The contract, first offered on the recommendation of Sir Roderick Murchison, was renewed several times. His surveys covered much of the colony and added greatly to geographical knowledge of western Tasmania. He named peaks along the West Coast Range after contemporary English scientists. He also served as a coal commissioner from March 1862 to June 1867, as a gold commissioner of the western district in 1862 and a magistrate of the territory.

Gould's wide experience, careful observation and well-developed stratigraphic and structural senses led to the first establishment of the order and correlation of Ordovician to Lower Devonian rocks over much of Tasmania, to the correct deduction of the succession of Permian and Triassic coals and Jurassic dolerite and to the suggestion of mining for coal under dolerite sills as along the Mount Nicholas Range, the development of which he strongly urged. The first recognition of glacial deposits in Tasmania was his. His strategy in looking for gold was sound and economical and his results, though negative, still stand. He tried to make the public aware of the dangers of relying too much on analyses of single samples.

An impression of incompleteness is conveyed by his reports and papers; something more or better soon was a common promise and the colonial secretary did not always get the reports when he wanted them. Another area of continuing tension was that of the function of the Survey: Gould wanted a regional geological survey and the secretary a mineral prospecting unit, preferably one for gold; but the final compromise was rather closer to Gould's stand. Combined with these difficulties, the depressed finances of the colony in 1868-74 probably led to the lapse of Gould's contract in August 1869. Gould then seems to have acted as a geological consultant and land surveyor in Tasmania, the Bass Strait islands and New South Wales where he was licensed as a surveyor on 29 January 1873. While in Tasmania he was actively interested in its Royal Society and the fauna and flora. He left Tasmania late in 1873 and seems to have returned to London where he stayed until at least June 1874. From 1880 he travelled in Burma, Singapore, Siam, Hong Kong, China, Korea and Japan, apparently advising on mining properties. He also collected ornithological specimens and material for his *Mythical Monsters* (London, 1886), a rather credulous book, the culmination of an interest extending at least as far back as his Tasmanian days. He returned to Europe early in 1889 but soon sailed to Buenos Aires. He travelled in South America until he died, probably unmarried, in Montevideo, Uruguay, on 15 April 1893.

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MAXWELL R. BANKS
M. L. YAXLEY

GOWLLAND, JOHN THOMAS EWING (1838-1874), naval officer, was born on 10 July 1838 at Leysdown, Kent, England, the eldest son of Captain Thomas Sankey Gowlland and his wife Mary, née Ewing. He entered the Royal Naval School, Greenwich, became captain of its 800 boys and in 1853 joined the navy as a master's assistant. He saw active service with the Baltic squadron in the Crimean war and at 16 won a medal for taking a prize back to England. He then served in the survey of the Chincha Islands off Peru, of Vancouver Island and Straits and in determining the northern boundary of the United States of America. As a commander he won the goodwill of the Indian chiefs and was specially thanked by the Admiralty for his excellent charts; his name is perpetuated in several places on the Pacific coast. He returned to Europe by way of Sydney and as first assistant surveyor worked in the Mediterranean.

Gowlland was appointed to the Australian survey as chief assistant in 1865.

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Stratigraphic Nomenclature in the Precambrian

ALAN SPRY* AND MAXWELL R. BANKS*

Abstract

Present methods of correlation do not yet allow the application of *time-rock* terms to Precambrian rocks, although radioactive age determinations give hope of such correlation in the future. At present only *rock* terms are justifiable. The development of time divisions of world-wide applicability will follow the wide use of radioactive determinations.

Introduction

Examination of recent papers on the Precambrian of Australia, especially those in the volume on the 'Geology of Australian Ore Deposits', reveals that there are at present two methods of naming Preçambrian stratigraphic units, one involving the wide use of *time-rock* terms, the other involving the equally wide use of *rock* terms. This duality of practice raises the question of the correct procedure in naming strata when little or nothing is known of their time relationships.

Categories of Correlation

Three categories of terms are recognized in both the American and Australian Codes of Stratigraphic Nomenclature (Raggatt, 1950, 1953), i.e. *time* terms, *time-rock* terms, and *rock* terms.

In practice all categories are used by different groups of geologists for different purposes. All geologists use *rock* units and to many they are the only category of units required for adequate description and presentation of the geologist's observations. Thus most geologists, dealing with mining, oil, or engineering works and structures are mainly concerned with discrete lithological units, their disposition, properties, contents, and correlation. This group of geologists is not concerned whether or not the boundaries of their *rock* units transgress isochronous surfaces as is frequently the case. A number of methods of purely *rock* unit correlation are available and will be discussed in the next section. A more fundamental type of correlation is that between *time-rock* units, and this type of correlation is essential for the elucidation of the geological history of an area and its comparison with that of other parts of the world.

The fundamental difference between the different types of correlation should be appreciated. It is emphasized that most correlation in the Precambrian is *rock* unit correlation and consequently it is not permissible to draw similar conclusions to those deducible from a *time-rock* correlation.

Evaluation of Methods of Correlation Applied to the Precambrian

In naming Precambrian units it is necessary to consider the value of the method of correlation adopted as an indicator of contemporaneity. Details of methods are given by Hedberg (1954).

A high degree of correlative accuracy is attainable by walking the outcrop and this method of correlation and mapping is very widely used. Fundamentally, however, this method can yield only a *rock* unit correlation and its value in determining contemporaneity of beds in different areas will depend on the type of sediment.

Beds in different sections are frequently correlated because of similar lithology, but the accuracy of this method depends on the type of rock chosen. Some rock types have a high degree of time correlation within a single basin of deposition and others have a very distinctive lithology and so may be recognized easily. Where a rock has both these properties it is a most useful time indicator.

One bed may be correlated with another if both occupy similar positions in similar sequences, especially if the sequences contain a bed of distinctive lithology (key bed). A sequence of beds of different kinds and thicknesses is likely to be more uniform across a basin than a single bed alone. This method of correlation is lithological only and is applicable only within a single basin.

The degree of metamorphism or deformation is often used to correlate Precambrian rocks. It is the basis of the division of the North American Precambrian into Archaean and Proterozoic. It must be emphasized that an entirely separate concept is introduced by this division and the divisions are metamorphic facies rather than time divisions. The difficulties of using this method of correlation are numerous, the main one being that beds of the same age and lithofacies may exhibit entirely dissimilar grades of metamorphic alteration or structural deformation, even within the same basin of deposition, depending on their location in an orogenic zone. Thus this method of correlation can be used only with the utmost caution and within a restricted area.

Rocks have been correlated by virtue of their position above or below an unconformity. Unconformities can be used as time surfaces only with great caution as the significance of an unconformity may change radically from one place to another. Many inter-basinal

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correlations have been suggested on the basis of unconformities, but this implies simultaneous orogeny, uplift, subsidence, and sedimentation in widely separated areas, an hypothesis which is under considerable doubt at the moment (see Gilluly, 1949).

A method involving radioactive age determinations is the only one which yields completely objective results in terms of absolute time. In the past it has been applied to igneous rocks rather than to sediments, due to limitations of technique; but recently methods have been devised which make it possible to determine directly the age of some sedimentary rocks. When dealing with igneous rocks, the age obtained is that of the period of mineralization and thus of orogeny. The orogeny may have occurred long after sedimentation ceased and may affect rocks of quite different ages. Many Precambrian rocks have suffered more than one orogeny; and if the radioactive mineral was formed during the last deformation, the errors in correlation will be great. At present there is a method of correlation evolving which involves the establishment of a time framework on a large number of radioactive determinations of the ages of orogenies throughout the world. The various sediments are fitted between the dated orogenies and are then correlated with sediments having similar relations to similar orogenies in other countries. The degree of correlative accuracy at present is extremely low, but this method no doubt will become increasingly important as more age measurements are made.

The preceding brief discussion emphasizes the difficulty of making sound *rock* unit correlations within a single basin of deposition in the Precambrian and the even greater difficulty of making such correlations from one basin to another or from one continent to another.

Thus it is even more difficult to justify the use of *time-rock* terms in the Precambrian as they require the establishment of isochronous surfaces of wide extent and consequently only *rock* terms are usually justifiable. The use of a particular *rock* term should also generally be restricted to those areas where a high degree of correlative accuracy can be maintained. *Rock* unit correlations over long distances in the Precambrian are suspect.

Groups of rocks can be defined with reasonable objectiveness in the Precambrian in different parts of the world. Examination will probably reveal that some of these, or some parts of these, could justifiably be considered as *time-rock* units although only of *local* significance, so that a number of *local* subdivisions of geological time could be established. With the accumulation of radioactive age determinations, accurate time correlations from one basin to another within the one continent should become possible. At this stage the number of systems, series, and stages can be reduced, following the rules of priority, to a bare minimum necessary to include all the Precambrian rocks found on that one continent. Eventually inter-continental *time-rock* correlations should be possible and a number of true Precambrian Periods and Systems, enough to cover all of the time included in the Precambrian Eon, and of world-wide extent, could then be founded on properly defined type sections and adequate age determinations.

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The Geomagnetic Field in Upper Triassic Times in the United States

It has been argued[1] that magnetically stable rocks have a remanent magnetization in the direction of the geomagnetic field at the time of formation, and that the mean direction determined from samples collected through a considerable thickness of one rock formation is that of a dipole-field orientated along the axis of rotation of the Earth at that time.

Because of the possibility of special effects, such as magnetostriction, the view has been taken[2] that these assumptions are liable to be in error and that in consequence the inferences which have recently been drawn from palæomagnetic studies[1] concerning the occurrence of polar wandering and continental drift in the geological past are based on no substantial grounds. A test relevant to this discussion is to determine whether rocks of the same age within one continent give pole positions in agreement, although it must be remembered that the geological age of those rocks which are most strongly magnetized, lavas and red sandstones, cannot usually be established with precision because diagnostic fossils are often scarce or lacking.

Measurements on rocks of Upper Triassic age collected in the United States have recently been made in Newcastle, Cambridge and Canberra, as shown in Table 1. In all cases the number of samples was small but they were well spread stratigraphically. The Springdale Sandstone[3] was collected from Zion National Park, Utah, and those from the eastern United States from the lower Connecticut Valley, from the upper Connecticut Valley and from New Jersey. The pole positions calculated on the assumption of an average dipole field are given in Table 1 and are plotted in Fig. 1. The ovals of confidence of the pole positions overlap.

The pole based on measurements of the Upper Triassic Keuper Marls of England[4] and its oval of confidence is also given for comparison—it is believed that this discrepancy results from post-Triassic continental drift.

From these results three points of interest arise.

(1) They show that results from small numbers of samples can be quite reliable and provide a practical demonstration of the validity of the sampling methods advocated by Watson and Irving[5] and by Runcorn[6].

Table 1

Formation	No. of determinations	Mean direction			Sampling area		Pole position			
		D	I	α	Lat.	Long.	Lat.	Long.	dχ	dψ
1. Springdale Sandstone	18 disks from 8 samples	338	+16	—	37 N.	113 W.	55 N.	107 E.	—	—
2. Lavas near Holyoke, Mass.	8 samples (from 3 flows)	10	+14	11°	42 N.	73 W.	54 N.	90 E.	11	6
3. Lavas and sediments of Connecticut	12 samples	12	+14	15°	42 N.	73 W.	55 N.	88 E.	15	8
4. New Jersey (Brunswickian formation of Newark series)	71 disks (from 21 samples)	6	+28	3°	41 N.	75 W.	63 N.	93 E.	6	3

Mean directions of magnetization of Upper Triassic formations from the United States, specified by declination D reckoned eastwards from geographical north and the inclination I positive downwards. α is the angle of confidence at the 95 per cent probability-level. The semi-axes of the ovals of confidence of the poles, dψ and dχ, in the direction of and perpendicular to the great circle joining the pole and the site are given. The significance of α, dψ and dχ have been discussed previously (ref. 1).

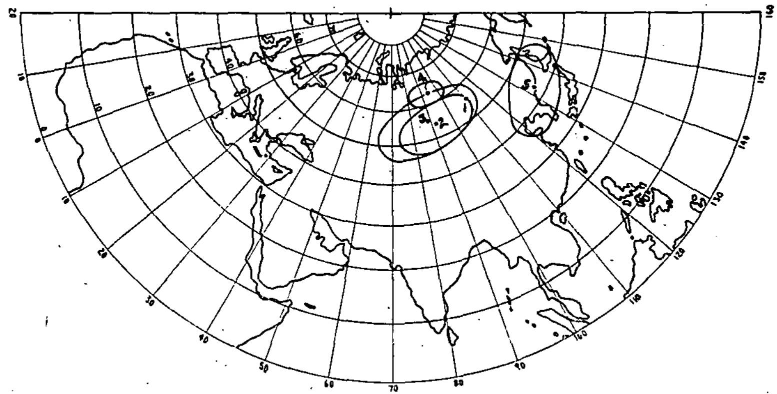

Fig. 1. Position of the geomagnetic pole in Upper Triassic times relative to the United States and Europe (polar stereographic projection). The determinations from rock formation in the United States are numbered as in Table 1. The equivalent pole determined from England is numbered 5

(2) Results from both igneous and sedimentary rocks laid down at approximately the same geological time but at points thousands of miles apart within the same continent are in agreement, and indicate the high degree of certainty with which these 'fossil' directions may be identified with the Earth's magnetic field during the Upper Triassic so that in these red sandstones and lavas it seems that the special effects mentioned above are of negligible importance.

(3) It seems reasonably certain that during this time the geomagnetic field over the region of the United States approximated on average to that of a dipole as it is known to have done since the Miocene[7,8]. The axis of this dipole intersected the Earth's surface in the regions of what are now central Siberia and southern South America.

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Paleomagnetic Results from the Upper Triassic Lavas of Massachusetts

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Abstract. The directions of magnetization at five sites in two lava members of the Newark group of Massachusetts have been measured. The directions have fairly consistent northerly declinations, but the inclinations are highly variable. This variation is shown to be due to the presence of a soft magnetic component of variable magnitude approximately parallel to the present earth's field, the effect of which is removed in alternating magnetic fields of 150 oersteds. The magnetization remaining after the removal of this 'soft' component has a mean direction (010°, +16°) which is consistent with the paleomagnetic pole position at 55°N, 88°E. This agrees well with other Triassic paleomagnetic pole determinations from the United States.

Introduction. In 1956 we collected 16 samples from two lava members in the Newark group of Massachusetts and measured their directions of natural remanent magnetization ($\mathbf{M}_n$). About one-half of these samples were stable magnetically, and from these a provisional mean direction and pole position was published [*Du Bois, Irving, Opdyke, Runcorn, and Banks*, 1957, second entry Table I] for comparison with paleomagnetic results obtained by others for samples taken elsewhere in the United States from Upper Triassic formations. The remainder of the samples contained a substantial viscous component of magnetization imposed by the present earth's magnetic field, and it has now been possible to demagnetize these components by treating the rock in alternating magnetic fields so that the underlying stable magnetization is revealed. This has been done so that all specimens may now be used, and the results, which supersede the earlier values, are given here. The number of sites visited (5) is not entirely satisfactory, but, since we have no opportunity for further sampling, putting the data on record is worth while.

Results. Several separately oriented samples have been taken from two sites in a lava in the Granby tuff [*Emerson*, 1917, map; *Bain*, 1941, p. 266], which becomes the posterior (Hampden) sheet farther south [*Bain*, 1941, p. 268], and three sites in the Holyoke lava member. Both lavas are members of the Meriden formation and part of the Newark group, the Holyoke lava member being older than the lava in the Granby tuff [*Rodgers, Gates, and Rosenfeld*, 1959, p. 16]. Sites and sampling details are given in Table 1. Two disk specimens (2.1-cm diameter, 0.8-cm thickness) have been cut from each sample. The directions and intensity of natural remanent magnetization in all specimens were measured and the directions corrected for geological tilt by simple rotation around the direction of the strike observed in adjacent sediments. These directions, which are plotted in Figure 1, have a predominantly northerly declination, but, with inclinations varying from +82° to −10°, the difference between specimens from the same site often exceeds 20° or 30°. Many of the directions tend towards the present field and it may be immediately suspected that comparatively 'soft' components of magnetization imposed recently by the earth's field are present.

In order to test whether or not such components are present, specimens were subjected to treatment in alternating magnetic fields in the absence of any steady field, using the apparatus and methods described by *Irving, Stott, and Ward* [1961]. Four specimens each from sites 2 and 5 were treated in alternating magnetic fields in steps of 75, 150, 225, and 300 oersteds (peak field H_p), measurements being repeated between each step. After treatment of the speci-

TABLE 1. Summary of Results

Lava Member	Site	Attitude: Azimuth, deg	Attitude: Dip, deg	S	N	$\mathbf{M}_n$: $D°$	$\mathbf{M}_n$: $I°$	$\mathbf{M}_n$: R	$\mathbf{M}_n$: k	$\mathbf{M}_n$: $\theta°$	$\mathbf{M}_{(150)}$: $D°$	$\mathbf{M}_{(150)}$: $I°$	$\mathbf{M}_{(150)}$: R	$\mathbf{M}_{(150)}$: k	$\mathbf{M}_{(150)}$: $\theta°$
Granby	1. Road cutting near Notch Quarry on Route 116 (72°31′25″W, 42°17′40″N)	090	12S	3	6	009	+52	5.89	45	12	014	+37	5.96	125	8
	2. Mountain Park, road cutting on Route 5 near Mt. Tom Reserve (72°36′30″W, 42°16′11″N)	019	12E	3	6	353	+43	5.39	8	29	357	+21	5.98	250	5
Holyoke	3. Farmington, road cutting on Route 6 (72°49′33″W, 41°42′09″N)	355	15E	3	6	355	+16	5.91	55	11	001	+18	5.95	100	8
	4. Ashley Ponds, road cutting on Route 202 (72°39′42″W, 42°10′04″N)	023	13SE	4	8	017	+13	7.89	64	10	020	+03	7.92	88	9
	5. Notch Quarry, quarry on Route 116 (72°31′25″W, 42°18′20″N)	078	19S	3	6	032	+26	4.94	5	36	014	+01	5.78	23	17

Notes: The site details and attitude of sediments adjacent to the collecting sites are given in the first three columns; the attitude is given by the strike azimuth and the dip. S is the number of samples and N the number of specimens. The values in the columns headed $\mathbf{M}_n$ and $\mathbf{M}_{(150)}$ refer to the natural remanent magnetization and the magnetization after treatment in 150 oersteds alternating field; D and I are the declination and inclination of the mean site directions corrected for attitude, R is the resultant, k is a measure of the within site precision [*Fisher* 1953], and θ is the circular standard deviation of the specimen directions (a cone of half angle θ whose axis is the mean direction contains approximately 63 per cent of the observed directions).

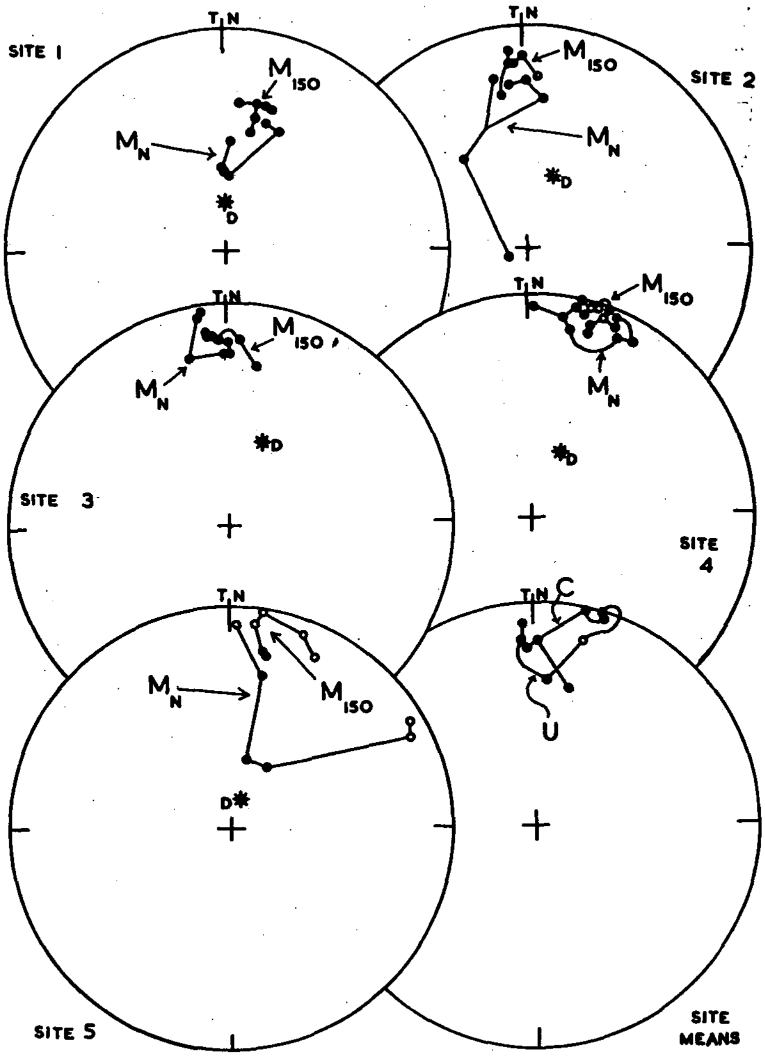

Fig. 1. The observations at each site are plotted on the first five of these equal-area nets, the primitive in each case being the bedding plane measured in adjacent sediments. The initial directions, M_n, are linked together as are those, M_{150}, measured after treatment of the specimens in an alternating magnetic field of 150 oersteds. In all cases the within-site precision improves, this being particularly apparent at sites 2 and 5 where the initial directions often tend strongly towards the present field. At sites 3 and 4 the magnetizations show greater stability. The dipole field direction is labeled D. At bottom right, the site mean directions are plotted before (U) and after (C) correction for the attitude of the beds. In all cases solid dots indicate directions with positive inclination and circles denote negative inclinations.

mens in a field of 150 oersteds the agreement between specimens from the same site was much improved, but in higher fields the directions began to scatter. It is considered that the treatment in 150 oersteds effectively demagnetizes the viscous components, and specimens from all sites have been treated in this way. The agreement in directions both within and between sites is now much improved (see Table 1 and Fig. 1). The inclinations are now all low or moderate.

Many of the specimens, considered individually, were stable, their directions changed little, and their intensities diminished only slowly in increasing alternating magnetic fields; an exam-

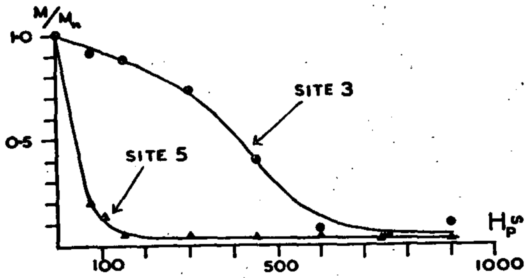

Fig. 2. Effect of alternating magnetic fields on the intensity of magnetization. The ratio of the moment M after treatment to the natural remanence M_n is plotted vertically, and the peak alternating field applied ($H_{\tilde{p}}$) along the horizontal axis. The upper curve (dots are experimental points) is for a specimen ($M_n = 1.61 \times 10^{-3}$ emu/cm³) from site 3 (Holyoke lava member), and the lower curve (triangles are experimental points) for a specimen ($M_n = 1.03 \times 10^{-3}$ emu/cm³) from site 5 (Holyoke lava member). These graphs illustrate the variability in stability found within the same lava member.

ple, from site 3 (Holyoke lava member), of the demagnetization curve of such a specimen is given in Figure 2. In this specimen the directions after treatment in a field of 150 oersteds changed by only 5°. In other specimens the magnetization is less stable; their directions, which were initially not far from the present field, change, after treatment in the 150-oersted field, so that they always agree closely with those from stable specimens. The demagnetization curve falls steeply and is of a type characteristic of isothermal remanent magnetization. In these unstable specimens the major part of the natural remanent magnetization is secondary in origin and is aligned approximately along the present field. An example of such a curve from a specimen from site 5 (Holyoke lava member) is given in Figure 2; the directions shift after treatment in 150 oersteds by 46° away from the present field direction.

The over-all mean site direction after correction is (010°, +16°) and the error ($P = 0.05$) in mean (calculated from the over-all precision $k' = 184.5$) is 10°. The between-site precision, calculated by the methods described by *Watson and Irving* [1957], is 41. The mean site directions before and after correction for attitude are plotted in Figure 1. Correction produces a slight improvement in agreement, which indicates stability, but the dips are small and any large effect is not to be expected.

Discussion. The scatter between sites is clearly significant even within the same lava member. Each member may contain several flows, so that this scatter may be due to secular variation of the field during the period in which the magnetization was acquired; it may be noted that the scatter (circular standard deviation 13°) is comparable to the departures from the geocentric dipole field observed nowadays. The simple corrections applied for geological tilt may not always be an adequate restoration and could also be responsible for some of the scatter. For instance, the flexures advocated by *Bain* [1941, p. 265] for the area of Notch Mountain and farther east could have affected site 5 so that the directions should be (014°, −04°); however, the effect is small (cf. Table 1) and would not occur at the other sites.

The paleomagnetic pole positions consistent with the mean direction are 55°N, 88°E, and 55°S, 92°W, which compare very well with those obtained from the Triassic of Connecticut and New Jersey [*Du Bois, Irving, Opdyke, Runcorn, and Banks*, 1957; *Opdyke*, 1961] and also with those obtained from the Triassic of the western United States [*Collinson and Runcorn*, 1960]. This concurrence of paleomagnetic pole results from many different rocks over such a wide area indicates that a dipolar axis with this attitude provides a realistic representation of the Triassic field in the United States. These determinations are, of course, relative to the sampling region only and do not mean that central Siberia was on the paleomagnetic pole at that time; in fact, recent work by *Makarova* [1959] on the Triassic Siberian traps of the Yenesei region indicate that this was not the case.

The inclinations in the lava in the Granby tuff are usually about 10° steeper than those observed in the Holyoke lava member, although it is not possible to test the significance of this difference from the present data. However, it may be possible by more extensive sampling along the outcrops, together with a similar extension of work farther south, to define characteristic direction for each flow and thus to test the correlation, usually assumed by stratigraphers of these lava flows in the upper part of the Newark group of the eastern United States.

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